OROVILLE FACILITIES RELICENSING
(PROJECT NO. 2100)

SP-F16
EVALUATION OF PROJECT EFFECTS ON INSTREAM FLOWS AND FISH HABITAT
DRAFT PHASE 1 REPORT

REVIEW DRAFT

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EXECUTIVE SUMMARY

The California Department of Water Resources (DWR) and other participating agencies have been collecting physical and biological data on the Feather River downstream of Oroville Dam for many years. One aspect of these studies is the application of the Instream Flow Incremental Methodology (IFIM) and its associated PHABSIM (physical habitat simulation) computer models which create indices describing the physical habitat suitability of alternative instream flow releases. PHABSIM incorporates highly technical hydraulic models linked to fish species habitat suitability criteria to compute these indices, and an independent review was requested by the Oroville Facilities Relicensing Environmental Work Group. All available reports, articles, and summary data were assembled by DWR and reviewed by the authors of this report. Information included instream flow study plans, data compilations, hydraulic data files, draft results, aerial photographs, fish spawning and rearing observations, and related materials.

The instream flow studies conducted by DWR provide a significant and useful tool for evaluating potential flow management strategies. The IFIM process used by DWR remains the most defensible method available for identifying and establishing environmental flows and is considered state-of-the-art internationally for in depth studies of flow and instream biota interactions. The studies are strong in terms of general river representation and the acquisition and use of site-specific habitat criteria data for the target fish species (chinook salmon and steelhead).

Two general areas of the DWR studies were identified as needing to be addressed to bring them to the highest acceptable standards. First, additional river study sites should be selected for supplemental hydraulic data collection using improved measurement and modeling techniques for the following reasons:

- the cross-sections (transects) used do not account for possible geomorphic change in the river since they were established and measured,
- some river habitat types were under-represented or not represented,
- the process of transect selection was not strictly objective, and
- partial transects (mostly split channels) were merged in with complete ones.

At least twelve one-dimensional transects are recommended, along with two two-dimensional sites, after which all hydraulic data should be recalibrated. Second, supplemental biological data should be collected (much of which is currently being acquired by DWR) to strengthen information on aspects such as:

- focal versus mean column velocity use,

- use of greater depths by larger fish, and
- correction of habitat use data with habitat availability data.

Following completion of this data collection effort, all data should be pooled together and new final habitat suitability criteria created and linked with the hydraulic data to create new flow suitability indices.

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INTRODUCTION/BACKGROUND

In 1995, the Feather River Technical Team (FRTT) of the Anadromous Fish Restoration Program Core Group listed instream flows as the key limiting factor for chinook salmon and steelhead production in the Feather River (USFWS 1995). The FRTT further suggested that inadequate flows may limit spawning and rearing habitat for anadromous salmonids.

Minimum flows in the Feather River downstream of the Fish Barrier Dam were established by a 1983 agreement between Department of Water Resources (DWR) and California Department of Fish and Game (DFG). The agreement establishes criteria for flow for the reach of the Feather River from the Fish Barrier Dam to the Thermalito Afterbay Outlet and the reach of the Feather River downstream of the Thermalito Afterbay Outlet to the confluence with the Sacramento River for preservation of salmon spawning and rearing habitat (DWR and CDFG 1983). The agreement specifies that DWR release a minimum of 600 cfs downstream of the Fish Barrier Dam for fishery purposes. This is the total volume of flows from the Thermalito Diversion Dam Outlet, the Thermalito Diversion Dam power plant, and the Feather River Fish Hatchery pipeline. The agreement also specifies minimum flow requirements in the Feather River downstream of the Thermalito Afterbay Outlet ranging from 1200-1700 cfs during the primary spawning and incubation period (October-February), and from 1,000-1,700 cfs during March, dependent upon Lake Oroville storage (greater than 733 feet) and normal unimpaired runoff (1,942,000 acre-feet) near Oroville. There is an additional requirement for this reach that if, from October 15 through November 30, the hourly flow is greater than 2,500 cfs, then the minimum flow must be maintained at no less than 500 cfs less than the hourly flow until the following March unless the high flow was due to flood control operation or mechanical problems. This requirement is to protect any spawning that could occur in overbank areas during the higher flows by maintaining high enough flows to keep the overbank areas submerged. In practice, the flows are maintained less than 2,500 cfs from October 15 to November 30 to prevent spawning in the overbank areas (DWR 2001).

The FRTT suggested that instream flow studies be completed to determine what flows might be required to enhance the river's salmonid stocks. Additional flow between the Fish Barrier Dam and the Thermalito Afterbay Outlet from September through May could enhance spawning habitat without an adverse effect on rearing (USFWS 1995). Initial results from a jointly conducted DWR and DFG instream flow study utilizing Physical Habitat Simulation (PHABSIM) suggested that spawning habitat in the reach from the Fish Barrier Dam to the Thermalito Afterbay Outlet would be maximized at higher flows than the present level of 600 cfs (DWR 1994). Additional PHABSIM analysis suggests that the maximum area of suitable spawning habitat in the upper segment was indicated to occur at a flow of approximately 1,000 cfs (Sommer et al. 2001). In the fifteen miles of river between the Thermalito Afterbay Outlet and Honcut Creek, maximum suitable spawning habitat area was indicated to occur at a flow of about 3,250 cfs (Sommer et al. 2001).

STUDY OBJECTIVES

A study plan to guide this review was prepared by the Oroville Facilities Relicensing Environmental Work Group (EWG 2002) in two phases with multiple objectives. The general objective is to analyze flow-habitat relationships to evaluate potential project effects on anadromous salmonid spawning and rearing habitat within the study area. The Phase 1 objective is to examine existing PHABSIM studies for their applicability to the needs of FERC Oroville Relicensing study plans. This includes an evaluation of the changes in the Feather River since these other studies were completed, as those changes apply to determination of the amount of available habitat. Additionally, this evaluation will include an assessment of the habitat suitability criteria generated in previous PHABSIM studies, as well as recent habitat utilization data collected by DWR. The objective of Phase 2, if necessary, will be to collect additional hydraulic or biologic data to supplement existing data for direct applicability to FERC Oroville Facilities Study Plans. Phase 2 will also establish tools to evaluate future potential operational scenarios and other protection, mitigation and enhancement measures (PM&Es).

This summary report of Phase 1 includes:

- Narratives of relevant findings by task, include the methodology and analytical procedures used in the review of each item, recommendations and discussions addressing relevant questions, and indications of any complications/data concerns
- Verification and/or development of habitat-flow relationships for the spawning and rearing life stages of chinook salmon and steelhead
- A description of the Phase 2 scoping process.

STUDY AREA

The study area covered by the Phase 1 evaluation consists of the 23.25 miles of the Feather River between the Fish Barrier Dam and Honcut Creek, which consists of two river segments. The first segment extends from the Fish Barrier Dam at river mile (RM) 67.25 to the Thermalito Afterbay Outlet (RM 59). Substrates in this segment are composed of relatively large elements with armoring due to transport of gravels downstream out of the area (Sommer et al. 2001). The river drops a total of 37 feet in this 8.25 mile-long segment, for a stream gradient of about 0.08 percent.

The second river segment is the reach of the Feather River which extends from the Thermalito Afterbay Outlet downstream to the confluence with Honcut Creek, near Live Oak (RM 44). The substrate in this segment of the Feather River tends to include relatively small gravel-sized particles transported from the upstream segment (Sommer et al. 2001). Stream gradient in this 15 mile-long segment is about 0.06 percent.

If a Phase 2 data collection effort is determined to be necessary, the geographic scope of the data collection effort will be specified in the Phase 1 summary report. The Phase 1 evaluation will include a review of the collected data regarding salmonid distribution and abundance in order to recommend potential expansion or contraction of the study area for Phase 2, if necessary. Study plans and phases of study plans approved by the Environmental Work Group (EWG) define the limits of the study area. If initial study results indicate that the study area should be expanded or contracted, the Environmental Work Group will discuss the basis for change and revise the study area as appropriate.

GENERAL APPROACH

The general approach of this Phase I assessment was to review and evaluate existing information and conduct additional analyses of existing data (site-specific or generic) using recent modeling and analytical techniques. This approach was intended to reduce uncertainty associated with previous PHABSIM analyses. The review of existing information and supplemental analyses are intended to identify whether additional data are needed to further refine flow-habitat relationships in the study area, and if additional data are required to specify required data collection efforts.

The Phase 1 review is composed of three tasks: 1) a review of existing studies and hydraulic and biological (habitat suitability) data; 2) a review of hydraulic and habitat modeling simulations; and 3) preparation of a summary report including identification of supplemental data needs. If it is determined that additional data are required following consultation with the EWG, then field surveys (to be described in the summary report) will be conducted in Phase 2 in order to complete a satisfactory description of stream flow-habitat relationships in the study area. If initial study results indicate that the methods and tasks should be modified, the EWG will discuss the basis for change and revise the study plans as appropriate.

PHASE 1 RESULTS

Task 1 – Review Existing Studies and Hydraulic and Biological (Habitat Suitability) Data

Task 1 of Phase 1 began by obtaining and reviewing existing hydraulic (Task 1A) and biological (Task 1B) information relevant to the SP-F16 study plan. Documents and sources utilized in the review are listed in Appendix A and cited where appropriate.

Task 1A – Review and Reassessment of Hydraulic Data

Hydraulic data for a PHABSIM analysis of the Feather River were collected by the California Department of Water Resources, in cooperation with the California Department of Fish and Game (Technical Team), at various flows between autumn 1991 and spring 1993 (DWR 1994). The stated purpose of the study was to evaluate the potential impacts on aquatic habitat of a proposed water transfer between storage releases in Lake Oroville and storage releases in the Yuba River (DWR 1992). Two study reaches were established: the reach of the Feather River extending from the fish Barrier Dam to the Thermalito Afterbay Outlet (also referred to as the upper reach or upper segment), and the reach of the Feather River extending from the Thermalito Afterbay Outlet to the Honcut Creek (also referred to as the lower reach or lower segment).

Review Note: The use of hydraulic data collected for evaluating a water transfer to evaluating the overall effects of the Oroville Project on instream flows and fish habitat represents a change from the written study purpose and scope. While the need to address other flow questions in the Feather River was most likely considered in study design, this is not expressly documented in the available information. This review will assume the data and results will be used for evaluating overall project effects and judge it accordingly.

Task 1A Category 1: Feather River Geomorphic Change Upstream of Honcut Creek

Transect data collection for the Feather River instream flow study was only partially completed prior to a large flood flow in 1993, an event which caused noticeable change in river channel geometry at a number of sites (DWR 1994). An even larger event occurred in 1997, which no doubt had substantial impact on the prior river channel geometry. Changes in channel geometry during data collection can have serious implications for the quality of hydraulic simulations (see Task 1A Category 2: Hydraulic Data Collection Methods and Equipment), but channel change over time is a separate issue. Standard study scoping for applying PHABSIM under the Instream Flow Incremental Methodology (IFIM, the approach used in the Feather River studies) specifies that a review of channel dynamics and stability is an important element of problem identification and study design (Bovee et al. 1998). Rivers can be either in a state of dynamic equilibrium or disequilibrium and a water development project can either affect this state or not. Major storage projects like Lake Oroville commonly have large effects on channel dynamics and stability through interruption of normal gravel transport and alteration of flow patterns (Collier et al. 1996).

The geomorphologic condition of the Feather River downstream of both Lake Oroville and the Thermalito Afterbay Outlet has been studied by DWR twice, once in the early 1980's and again in the mid 1990's, primarily for assessing salmon spawning gravel (Ross pers. comm.). The broad conclusion of these studies is that substrates in the Feather River have been progressively coarsening since the construction and operation of the project. This coarsening (winnowing of fines, sands, and gravels, leaving larger cobbles) has been more apparent in the reach of the Feather River extending from the Fish Barrier Dam to the Thermalito Afterbay Outlet than in the reach of the Feather River extending from the the Thermalito Afterbay outlet to Honcut Creek. Additionally, the rate of coarsening has lessened over time. Encroachment of riparian vegetation is also common downstream of storage reservoirs (due to lack of scouring flows) (Collier et al. 1996). The amount of riparian encroachment in the Feather River was probably affected by the 1997 high flows, but the current status is unknown.

Review Note: The progressive coarsening of substrates (and potential riparian encroachment) in the Feather River downstream of Lake Oroville will affect the results of instream flow analysis by reducing the "lifetime" or longer-term validity of any instream habitat modeling results. Under dynamic equilibrium, channel change or migration over time does not affect an aquatic habitat model; there will be very similar habitat-flow relationships, just in different places in the river. Channel degradation, however, will render the model inapplicable once a measurably new condition is reached. The rate of degradation determines the life of the study. It is very unlikely that the transects measured in 1992 and 1993 have remained unchanged post-1997, but whether the river has evolved to a new condition (aggraded or degraded) is unknown pending further geomorphic study. The safest approach to address this uncertainty would be to measure additional transects (recommended below), assign them weighting based on current habitat type proportions, and merge them with the existing transects to produce a habitat model with a larger data base. A larger habitat model with current cross-sectional data would be less sensitive to the potential effects of moderate channel morphology change.

Task 1A Category 1: Study Site Selection and Transect Placement

A multi-level approach to study site selection and transect placement was followed (Table 1, DWR 1992). Both study reaches (first division or Level 1) were mapped by habitat type using an approach similar to Morhardt et al. (1983), then divided into major channel features (Level 2), channel feature types (Level 3), and channel feature components (Level 4) using a system similar to Beak (1989). The identified major channel features were bar complexes and flat water areas. Bar complexes were separated into island complex, mid-channel bar, lateral bar, channel-spanning bar, and transverse bar, while flat water areas were separated into bend, straight, and split. Channel feature components were riffle, run/glide, and pool.

Review Note: The citation by DWR (1992) of Morhardt et al (1984) refers to the concept of habitat mapping for expanding transect data to study reaches, as opposed to using a "representative" reach containing transects weighted according to their presence within the representative reach. Level 2 and 3 habitat types were created specifically by DWR for the Feather River studies. The DWR channel feature components are less complex than those defined by Beak (1989), which included low gradient riffle, moderate gradient riffle, run/glide, shallow pool, and deep pool. Altogether, DWR created the potential for 24 habitat types and utilized 13 types during mapping (Table E-3, DWR 1992). Each of the mapped Level 3 habitat types within the two study reaches was named by either historic or geographic reference.

When selecting study sites, the Technical Team eliminated the area from the Fish Barrier Dam down to Table Mountain Boulevard Bridge "because of its relatively low habitat value." Level 3 channel feature types which comprised less than 15 percent of the total length of each Level 1 study reach were also not considered as study sites for transect placement. Remaining Level 3 channel feature types were then individually rated by hydraulics and habitat (good example of reach, little transverse flow, habitat diversity), background data (historic spawning, previous transects), and logistics (access, unlikely to be disturbed), using a one, two, or three star rating system (three stars being best). All individual ratings were then consolidated into an overall one or two star rating. Those channel feature types receiving an overall 2-star rating were selected more often for transect placement than were 1-star rated types.

Review Note: Even though the process was well described (Table 2, DWR 1992), the overall rating system was not strictly mathematical and contained elements of subjective judgment, both in the individual ratings and overall. While all sites with highest individual ratings (15 or more total stars) were given 2 stars overall and sites with low ratings (9 or fewer stars) were given 1 star overall, sites with intermediate ratings (10-14 stars) could be given either 1 or 2 stars. In addition, some 1-star sites had transects placed in them (Hwy 162 Bridge, Shallow Riffle) and some 2-star sites did not (Lower Eye, McFarland Riffle). This inconsistency demonstrates the undocumented influence of subjective judgment and compromises an objective review of the study site selection process.

Transects were placed in the selected study sites to have "three replicates of each [Level 4] habitat type… whenever possible, with an overall total of 32 transects" (DWR 1992). Specific locations were decided by distribution (upstream, middle, downstream) within habitat types, overlap with previous DWR transects, and inclusion of backwater habitat. While the study plan (DWR 1992) specified a target of 32 transects, 35 were initially identified and 31 ultimately used in the hydraulic and habitat index models (Table 1).

Table 1. DWR instream flow habitat unit name, channel type classifications, and transect use status

Habitat Unit Name	Channel Feature Type	Channel Feature Component	Use Status
Hatchery Riffle	Island Bar Complex	Riffle	Used
Auditorium Riffle	Straight Flat Water	Riffle	Used
Auditorium Riffle	Straight Flat Water	Run/Glide	Used
Auditorium Riffle	Straight Flat Water	Pool	Dropped
Highway 162 Bridge	Straight Flat Water	Pool	Used
Matthews Riffle	Straight Flat Water	Riffle	Used
Matthews Riffle	Straight Flat Water	Run/Glide	Used
Matthews Riffle	Straight Flat Water	Pool	Used
Aleck Riffle	Island Bar Complex	Riffle	Used
Aleck Riffle	Island Bar Complex	Run/Glide	Used
Aleck Riffle	Island Bar Complex	Pool	Used
Great Western Riffle	Straight Flat Water	Run/Glide	Dropped
Robinson Riffle	Island Bar Complex	Pool	Used
Robinson Riffle	Island Bar Complex	Run/Glide	Used
Robinson Riffle	Island Bar Complex	Riffle	Used
Weir Riffle	Straight Flat Water	Run/Glide	Used
Weir Riffle	Straight Flat Water	Pool	Used
Sutter Butte Riffle [1]	Straight Flat Water	Run/Glide	Dropped
Conveyor Belt Riffle [2]	Island Bar Complex	Pool	Used
Conveyor Belt Riffle [2]	Island Bar Complex	Run/Glide	Used
Hour Riffle	Straight Flat Water	Riffle	Used
Hour Riffle	Straight Flat Water	Run/Glide	Used
Hour Riffle	Straight Flat Water	Pool	Used
Goose Riffle	Straight Flat Water	Pool	Used
Goose Riffle	Straight Flat Water	Run/Glide	Used
Goose Riffle	Straight Flat Water	Riffle	Used
Big Riffle	Straight Flat Water	Pool	Used
Big Riffle	Straight Flat Water	Riffle	Used
Big Riffle	Straight Flat Water	Run/Glide	Used
Shallow Riffle	Island Bar Complex	Riffle	Dropped
Shallow Riffle	Island Bar Complex	Run/Glide	Used
Shallow Riffle	Island Bar Complex	Pool	Used
Herringer Riffle	Island Bar Complex	Riffle	Used
Herringer Riffle	Island Bar Complex	Run/Glide	Used
Herringer Riffle	Island Bar Complex	Pool	Used

[1] Included in Hamilton Slough
[2] Included in Big Hole Islands

Review Note: The exact process of transect selection and placement is not clear from the available documents and could be improved by a more detailed narrative discussion. However, sufficient detail is documented to provide a broad appreciation of the process, which is considerably more rigorous than normally followed in many instream flow studies. Even with the gaps in documentation, the use of four levels of stratification and subjective rating of all potential sites throughout the study area is still a relatively more sophisticated and defensible approach to study site and transect selection.

The end results of study site selection and transect placement can be summarized in the following tables, which use data extracted from the DWR reports. Table 2 summarizes the length in feet of each Level 3 channel feature type and Level 4 channel feature component between the Fish Barrier Dam and Honcut Creek, as derived from detailed habitat mapping.

Table 2. Summary of habitat types along the Study Area

Length of River (feet)					
	Pool	**Run/Glide**	**Riffle**	**Total**	**% of Reach**
upper segment					
Flatwater Bend	1000	0	0	1000	2.56
Island Bar Complex	6473	1698	2168	10339	26.46
Lateral Bar Complex	4487	350	0	4837	12.38
Mid-Channel Bar	700	0	0	700	1.79
Straight Flatwater	20799	645	755	22199	56.81
				39075	100.00
lower segment					
Island Bar Complex	24960	6910	8242	40112	46.18
Lateral Bar Complex	5949	800	350	7099	8.17
Mid-Channel Bar	195	732	48	975	1.12
Straight Flatwater	36150	1700	825	38675	44.53
				86861	100.00
Source: Table E-3, DWR 1992					

Table 3 identifies which channel feature type and component was represented by transects and how many transects were placed within each. In the upper and lower reaches, 16.73% and 9.29%, respectively, are not represented by transects and therefore are eliminated from the study.

Table 3. Final number and placement of transects by habitat type in the Study Area

Number of Transects					
	Pool	**Run/Glide**	**Riffle**	**Total**	**% of Reach**
upper segment					
Flatwater Bend	0	0	0	0	2.56[1]
Island Bar Complex	2	2	3	7	26.46
Lateral Bar Complex	0	0	0	0	12.38[1]
Mid-Channel Bar	0	0	0	0	1.79[1]
Straight Flatwater	3	3	2	8	56.81
				15	100.00
lower segment					
Island Bar Complex	3	3	1	7	46.18
Lateral Bar Complex	0	0	0	0	8.17[1]
Mid-Channel Bar	0	0	0	0	1.12[1]
Straight Flatwater	3	3	3	9	44.53
				16	100.00
Source: Appendix C, DWR 1994 [1] No transects placed, channel feature type not represented or otherwise included in study					

Combining the data from these two tables results in Table 4, the percent weight given to each transect in the DWR instream flow study, along with the percent of river not represented by transects.

Table 4. Percent weight of transects by habitat type in the Study Area.

Percent Weight of Transects (Total and Each)					
	Pool	**Run/Glide**	**Riffle**	**Study Total**	**% of Reach**
upper segment					
Island Bar Complex	19.39 (9.70)	7.63 (2.54)[1]	6.50 (2.17)	33.52	26.46
Straight Flatwater	62.29 (20.76)	1.93 (0.64)	2.26 (1.13)	66.48	56.81
				100.00	83.27
lower segment					
Island Bar Complex	39.68 (9.92)[2]	7.95 (2.65)	6.25 (6.25)	53.88	46.18
Straight Flatwater	43.10 (14.37)	2.03 (0.68)	0.98 (0.33)	46.12	44.53
				100.00	90.71

[1] Robinson Riffle split channel run/glide given double weight and three transects in category
[2] Conveyor Belt split channel pool given double weight and four transects in category

Review Note: The study site and transect selection process, while reasonable, did not expressly consider that transects should also be roughly equally allocated within habitat types to minimize both over- and under-representation. Assuming a finite number of transects were available (32 in this case), the transects would have been better allocated more to the predominant habitat types instead of by a rule of three replicates per habitat type. The consequence of the rule of three replicates per habitat type directed valuable field effort towards rare types (for example, run/glide and riffle habitats in straight flatwater with transects representing less than 1% of the study reaches) and less towards common types (straight flatwater pools, with each of three transects representing about 21% of the upper study segment). Habitat index results (weighted usable area) for broadly distributed species and life stages (like rearing fry and juveniles) will be driven by very few transects (5 in the upper segment representing 82%, 6 in the lower segment representing 83%). Results dominated by a few transects are more subject to simulation errors or unique characteristics of the data, and are less likely to correlate to fish population or distribution metrics. Habitat-specific species and life stage index results (such as for large fish in deep water or spawning fish on riffles) are less vulnerable to such transect weighting discrepancies.

Two other problems are worth noting. First, three transects were dropped (Great Western Riffle run/glide, Shallow Riffle riffle, and Auditorium Riffle pool) because various stage or velocity calibration errors were identified by DWR in the hydraulic simulations (DWR 1994). Loss of the Great Western Riffle run/glide was probably inconsequential (3 other low-weight straight flatwater run/glides remained). However, dropping the Shallow Riffle riffle left only one other island bar complex riffle, and dropping the Auditorium Riffle pool changed the weight of the remaining three straight flatwater pools from 15.6% each (high to begin with) to 20.7%. Data from additional transects in these habitat types is needed to reduce the high weight on a few transects. Second, two side channel transects representing less than the full channel width (Robinson Riffle run/glide and Conveyor Belt pool) were given double weight in the analysis on the recommendation of the Technical Team. This is not a desirable practice because flow splits between side channels rarely remain at a stable percentage over a range of flow (complicating a merge with non-split transects), and one part of a split channel can not be realistically assumed to represent equally the other part. These transects should be either reconstructed from existing data to include the entire channel or replaced by entirely new transects.

Finally, a paper by Williams (1996), which utilized this same data to test transect selection sensitivity and compute confidence intervals around composite WUA habitat index results, implied criticism of the underlying data and questioned the value of PHABSIM studies in general. The Williams paper should be viewed as presenting a conceptual idea for deriving WUA confidence intervals rather than as a valid critique of either the Feather River data or of PHABSIM itself. In his introduction, Williams states that confidence intervals can be calculated "provided that the sampling scheme includes random selection of transects." It is clear from the transect selection discussion above that the process in the Feather River was decidedly not random, so his basic assumption is violated. When transects are not random replicates, applying a bootstrap technique (as Williams did) will generate an entirely different physical picture of a river, which not surprisingly gives varied WUA in relation to flow. In addition, one pool transect in the upper segment (Figure 1, Williams 1996) and two (one riffle, one run/glide) in the lower segment (Figure 8, Williams 1996) have unique WUA trends (indicating they are not replicates), so inclusion or exclusion of these transects greatly affects his results.

<u>Task 1A Category 2: Hydraulic Data Collection Methods and Equipment</u>

The Proposed Study Plan (DWR 1992) describes in moderate detail the physical data collection procedures to be followed for the Feather River instream flow studies. DWR proposed relying on the methods outlined in the published PHABSIM field techniques guidance document (Trihey and Wegner 1981). Standard methods were anticipated, including velocity, depth, and water surface elevation data collection at three flow levels, and stable bed profile conditions were assumed while data were being collected. As commonly occurs, however, the realities of field work often interfere with the best intentions. DWR (1994) reports that data collection was not completed until after winter 1993, when flood flows in excess of 20,000 cfs changed the geometry of a number of the transects. This geometry change mostly affected the middle flow data point on the upper segment transects, meaning that only two (high and low) water surface elevations were available to calibrate the hydraulic models. DWR believed that flood flows did not cause similar major changes in the lower segment, where large flow fluctuations are more common and the channel may not be as sensitive to flooding.

Review Note: Channel geometry changes during data collection create a number of problems with application of PHABSIM to a river system. While change in bed profile over time is acceptable (assuming dynamic equilibrium), change during data collection violates the presumption of a fixed bed for modeling purposes. When the bed changes before all water surface elevation data are measured at three flows and only two (or fewer) points are available for any given profile, much quality control over depth simulation is lost. All three water surface elevation models in PHABSIM (IFG4, MANSQ, and WSP) virtually require three widely separated discharges to be measured to allow either log-log regression error checking (IFG4) or estimation of channel roughness change with discharge (MANSQ, WSP). Less than three measurement points requires much greater knowledge of hydraulic modeling than commonly available and substantially reduces confidence in the results. This appears to be a greater problem in the upper segment than in the lower, where fixed bed conditions apparently prevailed.

Other standard methods of data collection reportedly occurred as planned (DWR 1994). Permanent headstakes and benchmarks were established for lateral and vertical level control, both suspension and wading gear was used where suitable, meters were checked and calibrated frequently, staff gauges were monitored, at least two measurements (left and right bank) of water surface elevation were made on each transect, and discharge was calculated for each transect for comparison to others. Substrate and cover data were obtained concurrent with depth and velocity data.

Review Note: All standard methods reported to have been used are common to PHABSIM studies and have less error associated with them than some other methods. The use of cabling, suspension gear, top setting wading rods, and Price AA flow meters all add confidence to the probable quality of the field data. Quality control procedures such as meter calibration, staff gage monitoring, and field discharge computation all demonstrate good field technique. One missing topic is the type and quality of vertical level control, including the models of autolevels used, eyepiece magnification, accuracy standards for level loops, and reproducibility of headstake elevations. The actual number of water surface elevations across each transect is also not mentioned. Having only left and right bank data points is frequently inadequate to develop and assess the quality of stage-discharge simulations, even when three different levels of flow are measured.

<u>Task 1A Category 2: Hydraulic Model Calibration</u>

Appendix A of the DWR instream flow study results report (DWR 1994) describes in detail the data reduction and transect modeling methods used by DWR, including calibration and simulation of both water surface elevations and velocities. Water surface elevations were preferentially calibrated by fitting a log-log linear regression to the measured data of discharge and stage (minus stage of zero flow) using the computer program IFG4 within PHABSIM. If the fit of data to a log-log relationships was unacceptable, the MANSQ program was used as an alternative. MANSQ is typically used on transects which are hydraulic controls (e.g. riffles and many run/glides). For some transects with four data points, stage discharge relationships were split into high and low flow range simulations. Water velocities in each cell were calibrated and simulated using IFG4.

Review Note: A highly detailed review of the existing hydraulic simulation data would require copies of raw field data and calibration notes, possibly supplemented by interviews with field crews and modelers. This level of review would not be productive until other more significant problems are addressed. However, two general hydraulic simulation problems can be noted at this point. First, several of the transects in the upper and lower reaches were calibrated with only two stage-discharge pairs (N, Table 5), partly because not all data collection was completed prior to flood-caused channel change and a third pair could not be obtained and/or used. Calibration with two data pairs does not allow any quality control, since both IFG4 and MANSQ can be "calibrated" to zero error. Splitting a stage discharge relationship into high and low flow ranges is possible, but the method can also create two pairs of two data points, leading to a similar difficulty with quality control. While mean errors of regression in the DWR data (for transects with three or more data pairs) were mostly low (<5%) and slope beta coefficients (B) were mostly within normal range (2.0-5.0), the a-intercept coefficients (A) showed considerable variability (Table 5). The variability warrants further examination, because transect rating curves from the same river segment should have similar intercepts as well as similar slopes. Part of this variability may be due to inaccurate stage-of-zero-flow values, which are subtracted from the stage data in the log-log regression against discharge. These plotting stage values (Stage minus SZF) should be very similar for all transects, since they *represent the downstream hydraulic controls. The range of values in the upper segment is reasonable (determined at 400 cfs), but excessive in the lower segment (determined at 1000 cfs). Another contributor to variable a-intercept coefficients could be either error in field stage measurements or insufficient number of measurements on non-flat water surfaces. Only detailed examination of the field data and testing of alternative choices may be able to reduce the variability, which cannot be done arbitrarily.*

Table 5. Feather River instream flow study stage/flow regression statistics

XS	Name	N	A	B	MeanErr(%)[1]	Variance	Stage-SZF
Low Flow Channel							
1	HATCH C IBCR	2	10.2644	4.1063	0.0002	0.0000	2.44000
2	AUDIT 2 SFWG	2	19.6826	2.9251	0.0005	0.0000	2.80000
3	AUDIT 3 SFWR	2	2.3128	4.7485	0.0000	0.0000	2.96000
4	HWY 162 SFWP	3	80.7879	2.3144	0.5349	0.0559	2.00000
5	MATHW 1 SFWP	3	173.1881	2.6367	0.8760	0.1504	1.37000
6	MATHW 2 SFWG	3	192.7439	2.4254	1.7352	0.6025	1.36000
7	MATHW 3 SFWR	3	52.8381	2.9131	0.6194	0.0750	2.00000
8	ALECK 1 IBCP	2	114.6715	1.9308	0.0000	0.0000	1.91000
9	ALECK 2 IBCG	2	49.5742	2.4317	0.0003	0.0000	2.36000
10	ALECK 3 IBCR	2	58.6559	2.3937	0.0000	0.0000	2.23000
11	ROBIN 1 IBCR	3	235.7520	1.6549	1.7971	0.6476	1.39000
12	ROBIN 2 IBCG	3	30.5969	2.0787	0.5921	0.0684	1.88000
13	ROBIN 3 IBCP	2	29.3164	2.8773	0.0005	0.0000	2.48000
14	WEIR 1 SFWP	3	105.1252	2.2970	3.9447	3.4711	1.82000
15	WEIR 2 SFWG	3	92.7137	2.3616	1.7931	0.6447	1.87000
High Flow Channel							
1	HERRI 1 IBCP	3	7.9613	4.1330	0.0468	0.0010	3.22000
2	HERRI 2 IBCG	2	56.5745	2.4827	0.0001	0.0000	3.18000
3	HERRI 3 IBCR	2	57.9147	2.3511	0.0011	0.0000	4.96000
4	SHALL 1 IBCP	3	6.0128	2.5461	3.0029	5.1353	7.44000
5	SHALL 2 IBCG	2	1.9711	3.5541	0.0002	0.0000	5.77000
6	BIG R 1 SFWG	3	0.0561	5.1870	0.1960	0.0165	6.60000
7	BIG R 2 SFWR	3	145.0754	2.4102	0.8922	0.3230	2.23000
8	BIG R 3 SFWP	3	0.7627	4.2085	2.6526	2.3948	5.55000
9	GOOSE 1 SFWR	3	12.0666	3.0544	1.8823	1.2941	4.29000
10	GOOSE 2 SFWG	2	13.4490	3.0236	0.0018	0.0000	5.63000
11	GOOSE 3 SFWP	3	1.2472	4.2891	2.2576	1.8006	4.79000
12	HOUR 1 SFWP	3	0.1964	4.6228	4.2470	5.3969	6.36000
13	HOUR 2 SFWG	3	37.1252	2.6785	2.0325	1.4877	3.46000
14	HOUR 3 SFWR	3	92.5462	2.4858	2.4796	2.1260	2.64000
15	CONVY 1 IBCG	3	0.0694	5.3995	4.7005	6.1949	5.94000
16	CONVY 2 IBCP	3	0.0054	6.2139	4.5357	5.8539	7.09000

[1] Mean error is the average difference between measured WSEL and regressed WSEL and may have a non-zero value for a two-point regression because of differences in significant digit computations.

The second problem relates to the calibration of velocities and subsequent habitat simulations. Large rivers like the Feather typically have very low (near zero) velocities along the shallow channel margins and in backwaters. At higher flows, these locations will increase substantially in velocity, especially in backwater channels when water begins to enter from upstream. Many transects were calibrated to retain the pattern of near zero observed velocities upon *extrapolation to higher flows, resulting in unrealistic simulations and inaccurate weighted usable area values. An extreme example is Weir 1 shallow flatwater pool, where a large percentage of WUA for fry and juvenile chinook salmon for the whole upper segmentreach is coming from one part of one transect. Cells in this portion of the transect were calibrated to near zero velocity by hard-entering 0.01 velocities into cells at which a velocity was not physically detected. Instead of "borrowing" a cell roughness coefficient from an adjacent cell with a higher velocity, this method (0.01) assures a very high roughness and near-zero velocity over all simulated flows. Figure 1 shows bottom profile (black line), water surface elevation for 2500 cfs (blue line), velocity pattern for 2500 cfs (green line), and cell probable suitability (vertical bars). All higher velocity is near the center of the stream channel and only very low velocity is allowed to be simulated outside the center. Since all margin areas also correspond to high suitability for substrate/cover in the DWR study, most WUA results for fry and juvenile rearing (high vertical bars) derive from this type of margin cell velocity error. Figure 2 illustrates upper segment reach habitat index simulation results with and without only a single transect (Weir 1) out of the 15-transect data set and shows considerable difference in peaks and trends of WUA. Velocity calibrations in the channel margin areas of both reaches need to be changed to make simulations more realistic over a broader flow range. This recalibration should be part of a comprehensive Phase 2 reanalysis of data, incorporating additional transects and other recommended changes. Recalibration alone under Phase 1 would not sufficiently address the broader problems found in the study.*

<u>Task 1A Category 2: Unused Cross-Sectional Transects</u>

As previously discussed, three transects were dropped from the analysis after field data was collected (Great Western Riffle run/glide, Shallow Riffle riffle, and Auditorium Riffle pool). Dropping the first probably had little practical effect, since three other low-weight straight flatwater run/glides were retained. Dropping the latter two transects, however, is of greater significance because there were generally fewer transects of similar type and weight remaining. Two other transects were in split channel areas where only one side of the split was used (and doubled in weight as compensation).

Review Note: Detailed review of the field data and calibration of these five transects is deferred until additional data is collected, because even recovery and use of all five will not result in an acceptable number and weighting of transects. Too much weight would still have to be given to pools in both island bar complex and straight flatwater habitats in both study segments, and other complex (and most likely highly utilized) habitats have not been included (e.g. lateral bar complex). Some of these transects were likely dropped in error based on Technical Team review of velocity adjustment factors(VAF) that specified an "acceptable" VAF range of 0.8-1.2. This is the range for an archaic three-flow velocity regression simulation, not the one-flow Manning's n simulation which was actually utilized in the DWR Feather River studies (and has an acceptable VAF range of 0.1-10.0).

Task 1B – Review and Assessment of Biological and Habitat Data

Habitat Suitability Criteria (HSC) are a vital component of instream flow studies using either one-dimensional hydraulic models (i.e. PHABSIM) or two-dimensional models (e.g. River2D). HSC describe the relative "suitability" of several hydraulic-related components of the physical habitat for aquatic species. The habitat components that are typically included in HSC are depth, mean column velocity, substrate and/or cover. In some instream flow studies additional variables such as focal velocity, shear characteristics, distance to bank, etc. are incorporated into the model. HSC are typically created from "micro-habitat" data collected at observed focal positions of the target species. In the Feather River downstream of Oroville Dam, micro-habitat data was collected specifically for HSC creation for spawning and juvenile rearing chinook salmon as part of the DWR instream flow studies (DWR 1994). In addition, micro-habitat data has been collected for juvenile chinook salmon and steelhead since 1998 as part of DWR salmonid distribution and abundance studies. The following summaries were taken from various DWR reports, memorandums, site visits (2), and personal communications (DWR 1991, DWR 1993, DWR 2001, Sommer et al. 2001, DWR 2002a, DWR 2002b, Brad Cavallo, DWR, pers. comm.).

Task 1B Category 1: Sources of Data Available for HSC Development

Site-specific micro-habitat data was collected for spawning chinook salmon in 1991 and in 1995, for rearing juvenile chinook salmon in 1992, and for rearing juvenile chinook salmon and steelhead from 1998 to 2002.

Chinook salmon Spawning. Micro-habitat characteristics were measured at 212 chinook salmon redds in October 1991. Data was collected in an area within 100 ft of 32 transects previously established for the PHABSIM study. Transects included in the spawning study were distributed in the upper segment (600 cfs upstream of the Thermalito outfall) and the lower segment (1,000 cfs), and in pools, run/glides, and riffles. All redds were observed in riffles or run/glides. An additional 205 redd measurements were collected in the fall of 1995 under a higher flow regime (1,600 cfs in the upper segment and 2,500 cfs in the lower segment). Besides the redd measurements, 200 measurements of depth and velocity were taken at "unoccupied" locations within the search area to represent the "availability" of habitat conditions that were not chosen by spawners.

1992 Chinook salmon Rearing. Micro-habitat data was collected at 464 focal positions of fry and juvenile chinook salmon in the Feather River during 1992. All observations were made within 100 ft of 19 transects previously established for the PHABSIM study. Transects were located in both the upper segment and lower segment, and in pools, riffles, and run/glides, although sampling effort emphasized pool habitats according to a proportional design. HSC were created by DWR for fry (<2 in) and for larger juvenile chinook salmon.

Broad-Scale Surveys. As part of ongoing DWR distribution and abundance surveys, a dive crew conducts once per year "broad-scale" surveys which essentially encompasses the entire study area from the Fish Barrier Dam downstream to Honcut Creek. Divers space themselves across the full width of the stream channel and count all observed fish. Although substrate and cover composition is recorded at each fish location, in general this method is not intended to assess micro-habitat characteristics of rearing fish or to create HSC.

Intermediate-Scale Surveys. Micro-habitat data was collected at 169 juvenile chinook salmon and 1,002 juvenile steelhead focal positions (2002 data not included) during DWR's 1999 and 2000 distribution and abundance study referred to as the "intermediate-scale" survey. Intermediate-scale surveys are typically conducted once per month (March through September) at ten permanent index sites, seven located in the upper segment and three in the lower segment. Habitat availability data was collected intermittently as major changes in flow occurred.

Fine-Scale Surveys. Micro-habitat data was collected at 192 juvenile chinook salmon and 164 juvenile steelhead focal positions during 2001 distribution and abundance studies, referred to as "fine-scale" surveys. Fine-scale survey sites are 25m long by 4m wide strips randomly selected from the stream margin area within a larger riffle:pool or riffle:run/glide complex. Twelve fine-scale sites occur in the upper segment and 12 in the lower segment. Most of the fine-scale sites are located within intermediate-scale index sites, with the remainder selected from other riffle sequences. The fine-scale surveys are also sampled monthly from March through August. Habitat availability was measured at 36 locations within each fine-scale site.

Task 1B Category 1: Sample Site Selection

Chinook salmon Spawning Surveys and 1992 Chinook salmon Rearing Surveys. All chinook salmon spawning HSC data and the 1992 rearing HSC data were collected at study sites based on the presence of a PHABSIM transect. The PHABSIM study originally contained a total of 31 cross-sectional transects which were relatively equally distributed between the upper segment and the lower segment (15 transects and 16 transects, respectively), and between pools (11 transects), run/glides (11 transects), and riffles (9 transects). The procedures used to select habitat units containing the transects, and the location of transects within the units, were described in section "Task 1A Category 1: Study Site Selection and Transect Placement".

All chinook salmon redd surveys were conducted immediately upstream and downstream of each of the 31 transects. Surveys included bank areas as well as midchannel areas (where the bottom was visible from the surface). SCUBA gear was used along two of the deeper pool transects as part of the 1992 juvenile rearing surveys (where divers also looked for evidence of old redds).

The 1992 chinook salmon rearing data was collected at 19 of the 31 transects, 10 from the upper segment and 9 from the lower segment. Eight of the transects were in pools, five in run/glides, and six in riffles, but some of the pool transects were sampled multiple times in order to increase effort in that habitat type according to a proportional sampling design (where the habitat types are sampled relative to their proportional availability). The selection of the 19 transects for juvenile rearing HSC was based on a "modified cluster sampling" approach (Sommer 2002). This involved: 1) dividing the transects up into the main channel types (SFW, IBC); 2) randomly selecting "clusters" within each channel type (a cluster would be group of 1-3 transects, e.g. Auditorium 1-3, Aleck 1-3); and 3) making sure that there was fairly equal representation of each of the habitat types (R, P, G). Diving was conducted immediately upstream and downstream of each of the 19 transects, starting along the stream margins and extending into the midchannel where the bottom was visible from the surface.

Review Note: The proportional sampling design (Bovee 1986) was commonly employed in the 1980's and early 1990's prior to the development of alternative HSC techniques, such as equal area sampling. Data collected using a proportional sampling design were typically "adjusted" by availability data in order to prevent biases due to oversampling certain habitat types and undersampling other types. There are several ways to adjust observational data for availability, each with various strengths and weaknesses.

Intermediate-Scale Surveys. Intermediate-scale surveys are conducted at ten permanent index sites, seven located in the upper segment and three in the lower segment. Each of the intermediate-scale index sites is associated with a riffle habitat, although the actual survey area typically includes run/glide and/or pool habitats immediately upstream and/or downstream. These sites were originally selected from among the 40 available riffle areas in the project area, based on availability of diverse habitat characteristics and the known presence of fish. More sites were selected in the upper segment than in the lower segment due to the greater abundance of fish upstream of the Thermalito Afterbay Outlet. Most of the intermediate-scale index sites are associated with island complexes, which are themselves closely associated with the formation of riffle habitats in the study area.

Fine-Scale Surveys. Fine-scale survey sites are 25m long by 4m wide strips randomly selected from the margin area within a larger riffle:run/glide complex. Twelve fine-scale sites are randomly selected each month in the upper segment and 12 in the lower segment from among 28 possible sampling areas. The 28 possible sample areas are representative of available riffle sequences in the study area, and were identified based on availability of diverse habitat characteristics and the known presence of fish.

Review Note: A primary reason for the emphasis on riffle complexes in this study was the original focus on juvenile steelhead, which appear to be closely associated with riffle habitats and island complexes.

Task 1B Category 1: Sampling Effort Allocation

The level of effort allocated within study strata (i.e. reach, channel type, and habitat type) can be expressed in terms of the number of study sites sampled, the number of transects surveyed by divers, the amount of time sampled by divers, or the surface area sampled by divers. In tables Table 6 through Table 9, a “n/a” indicates that data is probably available but was not included in the data sets reviewed to date. The values for the chinook salmon spawning survey are based on the 1991 survey only, as no site-specific details were received from DWR for the 1995 data. Sampling at the intermediate-scale is not conducted strictly within “transects”, therefore no values are given for number of transects surveyed. Also, all fine-scale surface area estimates are based only on transects that contained fish, so survey sites that did not contain fish (which are more likely in the lower segment) are not included in the following tables. The fine-scale values for the number of study sites and transects are based on the number sampled per month (which should be constant each month), whereas the surface area values are based on *cumulative* sums of all surveys that contained fish observations.

Effort by Reach. Overall sampling effort has been well distributed between the upper segment and the lower segment, with the exception of the intermediate-scale surveys which emphasize the upper segment. The larger surface area value for the fine-scale survey in the upper segment is misleading in this table because surveys not containing fish were not included with the data supplied by DWR to date (see Table 6).

Table 6. Sampling effort distribution by river segment

Reach	# Study Sites				# Transects Surveyed				Total Dive Time Units				Surface Area Surveyed Units			
	Spawn	1992	Inter	Fine	Spawn	1992	Inter	Fine	Spawn	1992	Inter	Fine	Spawn	1992	Inter	Fine
Upper Seg.	8	5	7	12	17	10	-	12	n/a	37	n/a	n/a	n/a	n/a	n/a	3,800
Lower Seg.	8	6	3	12	15	9	-	12	n/a	32	n/a	n/a	n/a	n/a	n/a	1,700
Total	16	11	10	24	32	19		24		69						5,500

Effort by Channel Type. The predominant channel types in the study area are referred to as "Straight Flat Water" and "Island Bar Complex". The intermediate-scale and fine-scale data sets received from DWR did not include the channel type, but that information can be derived from reference to habitat unit numbers and habitat maps. The spawning and 1992 juvenile surveys placed more emphasis on straight flatwater habitat (which is the predominant channel type in the study area) (see Table 7).

Table 7. Sampling effort by channel type

Channel Type	# Study Sites				# Transects Surveyed				Total Dive Time Units				Surface Area Surveyed Units			
	Spawn	1992	Inter	Fine	Spawn	1992	Inter	Fine	Spawn	1992	Inter	Fine	Spawn	1992	Inter	Fine
Straight FW	11	7	n/a	n/a	21	12	-	n/a	n/a	43	n/a	n/a	n/a	n/a	n/a	n/a
Island Bar	5	4	n/a	n/a	11	7	-	n/a	n/a	26	n/a	n/a	n/a	n/a	n/a	n/a
Total	16	11			32	19				69						

Effort by Habitat Type. Effort appeared to be relatively equal between habitat types for the chinook salmon spawning surveys, although dive times and surface areas have yet to be evaluated. The 1992 juvenile surveys placed greater emphasis on pool habitats due to the proportional sampling design. The unequal surface area estimates for the fine-scale surveys are likely to be misleading because the habitat type designations were made along the stream margins at a sub-habitat type scale, thus a particular fine-scale transect could have been predominantly designated as a glide even though the overall habitat unit (particularly the midchannel) was more characteristic of a riffle (these values can be re-estimated using habitat unit number rather than the sub-habitat type designations included in the data set). It is expected that overall effort in the intermediate-scale and fine-scale surveys will emphasize riffle and run/glide habitats over pools (due to the sample area selection design), and thus will help to balance the pool-dominated sampling of the 1992 juvenile surveys (see Table 8).

Table 8. Sampling effort by habitat type

Habitat Type	# Study Sites				# Transects Surveyed				Total Dive Time Units				Surface Area Surveyed Units			
	Spawn	1992	Inter	Fine	Spawn	1992	Inter	Fine	Spawn	1992	Inter	Fine	Spawn	1992	Inter	Fine
Pool	11	8	n/a	n/a	11	64	-	n/a	n/a	52	n/a	n/a	n/a	n/a	n/a	1,200
Run/Glide	12	5	n/a	n/a	12	20	-	n/a	n/a	7	n/a	n/a	n/a	n/a	n/a	3,400
Riffle	9	6	n/a	n/a	9	21	-	n/a	n/a	10	n/a	n/a	n/a	n/a	n/a	900
Total	32	19			32	105				69						5,500

Effort in Margin vs. Midchannel. Evaluating the relative distribution of effort along the stream margin versus the midchannel is difficult for the spawning and 1992 juvenile data sets. Although some HSC observations contained measurements of distance to bank, most of the spawning and juvenile data did not distinguish between bank surveys and midchannel surveys, and the relative effort expended in midchannels varied widely among transects according to habitat type, flow level, depth, etc. For the intermediate-scale surveys, specific diver observations can likely be related to habitat unit numbers that distinguish between bank and midchannel areas. However that data was not included in the data sets evaluated for this summary. For the fine-scale surveys, all sampling was conducted within 4m of the stream margin.

Review Note: Most HSC studies utilize some measure of effort to describe how sampling is allocated among study reaches and habitat types. The 1992 juvenile chinook salmon HSC study allocated approximately 66% of effort within "straight flatwater pool" habitat by proportional sampling design, because two-thirds of the available habitat in the study area was composed of that habitat type. More recent HSC studies are typically conducted using an "equal-area" sampling scheme where the same amount of effort is allocated to each habitat type. Equal-area sampling is better suited to HSC studies where habitat utilization data is directly pooled among all habitat types, because the relative number of fish observations per habitat type is related to the density of fish in those habitat types (which in theory is correlated with the quality of that habitat type), rather than related to the amount of effort expended making observations in that habitat type. For example, the 1992 juvenile chinook salmon data contains more chinook salmon fry observations in pools than in other habitat types, but that is due in part to the greater level of effort allocated to that type.

In most HSC studies, effort is measured in terms of surface area of sampled habitat, much in the way it is done in conventional studies of fish abundance. In some studies, as in the Feather River studies, effort is measured in terms of sampling time, which can be converted to catch-per-unit-effort (CPUE) which is another way of assessing fish density. Although sampling time and CPUE can be used to assess the relative levels of effort among reaches or habitat types, this measure of effort is somewhat imprecise because much of the sampling is conducted by diving which was typically conducted upstream along the stream edges (which is expected to be somewhat constant in rate) and downstream in the midchannels (which is not expected to be constant since divers will cover much more area per unit of time in swifter riffles than in slower pools). Consequently, the use of dive times or estimates of CPUE may leave questions regarding the relative levels of sampling effort per reach or habitat type. Unlike the 1992 survey and the intermediate-scale survey, the fine-scale survey is conducted within specified areas of 100m^2 each, and thus effort can be accurately assessed among reach and habitat type strata. Intermediate-scale surveys conducted in 2002 will also include estimates of diver search widths, which will allow estimation of the surface area sampled at each intermediate-scale site.

Task 1B Category 1: Available Sample Sizes

Using a size class definition of fry <50mm and juvenile ≥50mm (see discussion of size class definitions below), micro-habitat data is currently available for juvenile fish observations from the 1992 survey, the 1999-2000 intermediate-scale survey, and the 2001 fine-scale survey:

Table 9. Chinook salmon and steelhead observations by size and habitat type

	Chinook <50mm				Chinook ≥50mm				Steelhead <50mm			Steelhead 50-199mm		
	1992	Intermed	Fine	Sum	1992	Intermed	Fine	Sum	Intermed	Fine	Sum	Intermed	Fine	Sum
Pool	271	33	27	331	40	27	16	83	117	35	152	44	2	46
Glide	43	22	100	165	8	35	33	76	278	94	372	205	6	211
Riffle	57	2	10	69	47	45	6	98	51	13	64	240	10	250
Total	371	57	137	565	95	107	55	257	446	142	588	489	18	507

For chinook salmon spawning, the 212 redds measured in 1991 were mostly found in riffles (184 redds), with the remaining 28 redds in run/glides. No redds were observed in pool habitats. Habitat type information was not included with the 1995 spawning data transferred to TRPA, so the number of observations per habitat type cannot yet be assessed. It is clear, however, that the majority of chinook salmon spawning occurs in riffle habitats in the upper segment of the Feather River.

Review Note: All of the given sample sizes (summed across surveys and habitat types) exceed the recommended minimum of 150 to 200 observations (Bovee 1986) and, based on sample size, should be suitable for HSC development in the Feather River studies. The larger size range of juvenile steelhead and their frequent use of higher velocities may warrant splitting the juvenile size class into two classes (e.g. 50-100mm, >100mm). Although not yet evaluated, the available number of steelhead in the largest class may be less than the recommended minimum, although still possibly suitable.

Task 1B Category 1: Types of Data Collected at Fish Focal Positions

In addition to information describing fish species, type, number, habitat type, etc., conventional HSC studies typically collect total water depth, mean column velocity, substrate composition, and cover composition at the focal position of each observed redd, fish, or group of fish. Substrate and cover codes are frequently study-specific; these will be discussed in section ____, pg. ___. Many other studies collect additional micro-habitat data, such as focal (nose) height, focal (nose) velocity, velocity shear characteristics, distance to bank, etc. The types of data collected in each of the DWR studies conducted to date differ somewhat due to differences in methodology and differences in study goals.

Chinook salmon Spawning Surveys. Total depth, mean column velocity, and dominant substrate type was collected at the location of each observed redd in 1991. Subdominant substrate type and percent fines were also collected at some of the redds. In the 1995 redd survey, total depth and mean column velocity was collected, but substrate data was not. In 1995, total depths and mean column velocities were also measured at 200 locations not associated with redds.

1992 Chinook salmon Rearing. In the 1992 rearing HSC study, total depth, mean column velocity, dominant and subdominant substrate composition, percent fines, and cover composition was measured for each juvenile chinook salmon (or school of chinook salmon) observed. Although focal velocities were included in the database, most were copied from the mean column velocity because most of the observed fish were holding position near the midcolumn where the mean velocity was taken. Distance to bank was measured for some observations.

<u>Intermediate-Scale Surveys</u>. The DWR intermediate-scale and fine-scale surveys were originally designed to answer questions about the distribution and abundance of fish rather than focus on micro-habitat characteristics, and therefore information was not always collected according to conventional HSC studies. For example, total depth, focal (nose) velocity, substrate composition, and cover composition was measured for each fish observed during intermediate-scale surveys conducted in 1999 and 2000; however mean column velocities were not measured. Distance to bank was measured for some observations. In 2001, only substrate and cover composition was recorded for each observation.

Review Note: The lack of mean column velocity measurements will require estimation of those values from recommended supplemental data. For 2002 surveys from May onward, divers are collecting both focal velocities and mean column velocities for all fish observed in midchannel areas (greater than 4m from the bank). The relationships derived between mean column velocities and focal velocities from the new 2002 data will be used to predict mean column velocities from focal velocities measured in previous intermediate and fine-scale studies.

<u>Fine-Scale Surveys</u>. During 2001 fine-scale surveys, focal velocity was the only micro-habitat variable measured at the location of the observed fish. Total depth, mean column velocity, and substrate and cover composition were all measured within $1m^2$ habitat availability "cells". The attributes of the cell nearest a given fish observation were assigned to that fish observation. Given the placement of availability cells within the survey area (the cells covered 36% of the survey area and were essentially arranged in 1m strips every 3m upstream), a fish focal position could occur within an availability cell or up to 1.5m away from the measurement point of a cell.

Review Note: For those fish observations that occurred within an availability cell, the depth, mean column velocity, substrate and cover composition within that cell would be expected to be a close approximation of the micro-habitat conditions at the fish's focal position. For those observations that occurred outside of an availability cell, the micro-habitat conditions at the fishes focal position may or may not be accurately portrayed by the nearest availability cell. During new recommended 2002 sampling, both focal and mean column velocity will be measured at each fish focal position. As described above, the comparative data will be used to compute mean column velocities for the focal velocities previously measured. The collection of mean column velocities at fish focal positions in 2002 can also be compared to the availability velocities measured in the "nearest cell" in order to determine if those velocities can be used to characterize focal velocities from prior studies.

<u>Task 1B Category 1: Habitat Availability Data</u>

Some form of habitat availability data is available for each data set. For the chinook salmon spawning and 1992 juvenile rearing surveys, all HSC data was collected in association with PHABSIM transects that can be evaluated to estimate habitat availability under the flow conditions that existed during HSC sampling. In addition to the PHABSIM transect data, habitat availability (depths and mean column velocities only) were also collected at 200 "unoccupied" locations during the 1995 redd surveys. Although the definition of "unoccupied" points and the methods of selecting them have not yet been evaluated, it is likely that the unoccupied data set can be used as an additional source of habitat availability data for use in evaluating spawning habitat use in 1995. Habitat availability measurements have also been collected at intermediate-scale sites on an irregular basis (only following notable changes in flow). All fine-scale surveys included the collection of habitat availability data from a systematic sample of 36 locations.

Review Note: Measurements taken in the upper segment will likely be suitable for comparison with habitat use data due to the highly stable nature of streamflows and channel morphology in that reach. In contrast, the highly fluctuating flow characteristics of the lower segment and the intermittent collection of availability data at those sites may prevent a comparison of habitat use and habitat availability data in that reach.

<u>Task 1B Category 1: Standard Methodologies and Equipment</u>

The equipment used by DWR to collect micro-habitat data is generally similar to that used in conventional HSC studies, except for the current meter used in the 1999-2001 intermediate and fine-scale surveys. In those surveys, DWR utilized a "Global Flow Probe", which has (according to DWR) an effective range of 0.3 to 25 fps with an accuracy of 0.1 fps. Average velocity was recorded at a single location (at 0.6 total depth) after a two-minute interval, or when instantaneous readings stabilized, whichever occurred first. Data is now being collected during the 2002 season with conventional rotating cup meters ("AA" and "Mini" models) according to standard USGS procedures, utilizing a 40 second time interval and measuring velocities at multiple depths in deeper water.

Review Note: The minimum velocity range for the Global Flow Probe current meter is relatively high for use in HSC development, especially considering the frequent occurrence of chinook salmon or steelhead fry at near-zero velocities. Other discrepancies between the DWR micro-habitat studies and conventional HSC studies, such as unequal effort among habitat types, the lack of mean column velocity measurements, and inconsistency in cover coding systems, have already been addressed or will be addressed below.

<u>Task 1B Category 2: Fish Size-Class Definitions</u>

Fork lengths were eye-estimated by DWR divers for all juveniles observed during each of the micro-habitat studies, so the data is suitable for creating size-specific HSC from defined size criteria. Fish were previously classified as "fry" or "juvenile" only for the 1992 juvenile chinook salmon study in order to create HSC for the PHABSIM study. Fry were defined as all fish less than or equal to 2 inches, with juveniles over 2 inches. Two inches, or 50mm, is a frequently used length to classify salmonids into fry or juvenile life-stages.

Review Note: Initial analysis of the 1992 juvenile chinook salmon data suggests that 50mm is an appropriate size classification. However, analysis of intermediate-scale and fine-scale data for steelhead suggests that a smaller size criterion might be justified to better discriminate fry from juveniles for that species. Further analysis using the post-1992 data for juvenile chinook salmon and the 2002 data for steelhead will help to define the size ultimately recommended for fry and juvenile size categories.

<u>Task 1B Category 2: Compatibility of Substrate and Cover Codes</u>

Chinook Salmon Spawning Surveys. Cover was not assessed during the spawning surveys, and substrate data was collected only during 1991. Therefore there are no compatibility issues with the chinook salmon spawning data.

1992, Intermediate-Scale, and Fine-Scale Rearing Surveys. The substrate codes used in each of the rearing surveys are compatible in terms of size class definitions, with the only difference being 4mm used in 1992 to define the beginning of small gravel versus 2mm used in subsequent surveys. That difference is insignificant in part because all estimates were visual (i.e. eye-estimated) and thus do not have sufficient precision to distinguish between 2mm and 4mm particles. The primary difference in codes is in the number of categories, where the 1992 survey used ten, the fine-scale survey used six, and the intermediate-scale survey used four. The 1992 survey data and the fine-scale survey data can be condensed into the four-component code used in the intermediate-scale survey, but the intermediate-scale data cannot be further divided into either of the more complex codes.

Review Note: Because substrate composition is typically considered most applicable to specialized, substrate-specific life stages such as spawning and overwintering, converting the 1992 and fine-scale codes into the simplified intermediate-scale code for fry and juveniles is not expected to be difficult.

The cover codes used in the rearing studies have significant compatibility issues due to differences in size classification of cover elements. For example, the 1992 code used 2 ft to distinguish between small and large instream cover elements, whereas the intermediate and fine-scale surveys used 0.5 ft to make that distinction. Consequently, a focal position classified as having small instream cover in 1992 could be equivalent to the small cover (if less than 0.5 ft) or the large cover (if 0.5 ft to 2 ft) definition in the intermediate-scale or fine-scale surveys.

Review Note: A cover code compatible with the PHABSIM transect data should be possible to derive from the existing data if it is condensed into presence/absence of instream object cover and presence/absence of overhead cover. However, the utility and acceptance of such a code could fall under much debate. Another alternative would be to develop a cover code from only a specific set of data (i.e. from the 1992 data only, the Broad-scale data [substrate and cover were recorded for fish observations], etc.), but it would have to be compatible with the PHABSIM cover coding data. These alternatives will require additional analysis and consultation with the Environmental Work Group.

Task 1B Category 2: Existing HSC Curves

Habitat use HSC have been created only for the chinook salmon spawning data and for the 1992 chinook salmon rearing data; neither curve sets were adjusted using habitat availability data. HSC have not yet been developed from the intermediate-scale or the fine-scale survey data.

Chinook salmon Spawning HSC. Chinook salmon spawning HSC were created by DWR for the 1991 data, the 1995 data, and/or the combination of data using a variety of analytical methods. Non-parametric tolerance limits (NPTL) were applied to frequency distributions of the 1991 and the 1991 + 1995 data sets for depth and mean column velocity. Substrate HSC was created from the 1991 data (substrate data was not collected in 1995) by normalizing the frequency distribution to the maximum value. Alternative HSC were created from the combined 1991 and

1995 data for depth and velocity using a 3-point running mean filter. Finally, binomial HSC were created from the 1991 and 1995 depth and velocity data by assigning a suitability of 1.0 to the central 50% of all observations, and giving zero suitability to all observations outside of the 50% centroid. The binomial HSC were used to evaluate flows for the Sommer et al. (2001) publication.

Review Note: Binary HSC are not commonly used in California instream flow studies and the effects of such curves on habitat simulation results can be significant. See "Task 2 Category 1: Sensitivity of WUA to Hydraulic Data and Modeling Variables" for more discussion on the effects of binary HSC on estimates of WUA. To use binary criteria at the 50% level there must be confidence that the outlying data (which represents fully 50% of all observations) is not representative of suitable habitat. One possible application of this assumption is under conditions of extreme fish densities (e.g. downstream of fish hatcheries or other migration barriers) where local densities may far exceed carrying capacity. Although fish in excess of capacity would be expected to die or disperse to other areas, fish may "choose" temporarily to reside in low suitability habitat due to other factors (e.g. predation). In the case of chinook salmon spawning in the Feather River, the high density of spawners in the upper segment could either force some fish to utilize low suitability habitat (which would likely be excluded from binary curves), or would result in superimposition of redds in high quality areas. Both results may be evident in the upper segment.

Differences in the depth distribution of redds in 1991 and in 1995 (under higher flows) could justify the creation of two separate sets of spawning HSC.

Review Note: Although fish may have utilized different ranges in depth over the two years of survey, velocities were similar. In general, combining data from a variety of flow regimes is considered beneficial to creating robust HSC, therefore using the combined data set would be preferable to developing two independent HSC models. Two sets of HSC for the same species/life stage would also create difficult choices, such as exactly what flow is the transition threshold where one curve set or the other would apply, and would this threshold be the same for the upper segment and for the lower segment.

<u>1992 Juvenile Chinook salmon Rearing HSC</u>. HSC curves were created for the 1992 juvenile chinook salmon depth and mean column velocity data using a 3-point running mean to smooth frequency distributions of the fry habitat use data, and using NPTL for the juvenile habitat use data. Frequency histograms for dominant and subdominant substrate and for cover types were created and normalized to the largest value. The suitability values for substrate were then discarded and all substrate types were given a suitability of 1.0 due to the belief that substrate was not a driving variable determining microhabitat selection of fry and juvenile chinook salmon. The normalized cover suitability values were also modified by combining the data into two classes: with cover and without cover. The suitability without cover was calculated as the percentage of fish observed without cover to the total sample size. The suitability of cover present was assigned a value of 1.0. In the final PHABSIM analysis, the substrate and cover data was combined into a single code which multiplied the substrate suitability values (1.0 for all substrates) by the cover suitability values (1.0 for cover present, 0.30 or 0.22 for cover absent for chinook salmon fry and juveniles, respectively).

Review Note: The method used to calculate suitability of no cover is not consistent with conventional normalization methods. To normalize the suitability of no cover, the number of observations without cover would be divided by the number of observations with cover (since the with cover category is set to 1.0 by default). Normalizing the no cover category would yield suitability values of 0.41 for chinook salmon fry (versus 0.30) and 0.28 for juveniles (versus 0.22). If chinook salmon rearing data is pooled among the three DWR studies, including the 2002 data, new cover suitability values should be developed following analysis of cover coding options.

<u>Task 1B Category 2: Potential Differences in Fall-Run and Spring-Run Chinook salmon Habitat Use</u>

There is currently some speculation concerning the relative population characteristics (number of fish, size, timing, etc.) of fall-run chinook salmon and spring-run chinook salmon in the project area.

Review Note: Data is not currently available to determine if fish from the two run types spawn in different locations or in different micro-habitats. The possibility of locating and measuring enough spring-run chinook salmon redds to construct independent HSC for that run independently is highly questionable. It therefore seems most reasonable at this time to utilize the fall-run chinook salmon spawning data to represent spring-run chinook salmon.

<u>Task 1B Category 2: Rearing of Fall-Run Chinook Salmon</u>

Fall-run chinook salmon typically out-migrate at a young age with limited rearing in proximity to the spawning areas, and such a trait has been confirmed by DWR emigration studies.

Review Note: Although fall-run chinook salmon rear for a relatively short period of time in the study area, considerable growth occurs during that time, so in-river rearing is an important life-stage that should be included in any flow modeling activities. Micro-habitat use during outmigration has not been specifically addressed; however, many of the juvenile observations made in the lower segment may be from fish in the process of dispersing downstream. The differences (if any) between the micro-habitat requirements of pre-migrant, residential fish and actively migrating fish (during daytime "rest-stops") are poorly understood.

<u>Task 1B Category 2: Aspects of Spawning Characteristics and Requirements for Steelhead</u>

Relatively little is currently known about the spawning life-stage of steelhead in the study area. A complete review of current information and other sources of spawning HSC would be required prior to modeling habitat for that species/life-stage.

<u>Task 1B Summary: Strengths and Weaknesses of DWR HSC Data</u>

<u>Principal Strengths</u>. The DWR micro-habitat data has significant strengths in that sampling effort was well distributed temporally (spring to summer) and spatially (by study reaches), and was collected at a variety of flows (typically 600 cfs in the upper segment, higher and variable flows in the lower segment). Sample sizes by species and life-stage are very high when summed across all studies, which helps to alleviate data artifacts that often result from small sample sizes.

Habitat availability data was measured or can be estimated for most of the data sets for use in evaluating the effects of habitat limitations on habitat use data, or for developing HSC based on a ratio of habitat use/availability. Availability data may be unsuitable for such an analysis for the intermediate-scale survey data in the lower segment, but that data is not yet complete and has not been fully assessed.

Principal Weaknesses. Sampling effort was relatively equally distributed between the upper segment and the lower segment in most of the surveys, but the much higher fish densities that occur in the upper segment have resulted in the majority of data being collected from the relatively low and stable streamflow regime of that reach. If the quality of physical habitat is solely responsible for those differences in fish densities, an emphasis of HSC data from the upper segment might be appropriate. If, however, the lower fish densities of the lower segment are significantly affected by non-physical factors (such as water temperature, distance from spawning areas, predation, etc.), the relative lack of data from that reach could bias the resulting HSC curves.

The distribution of sampling effort among habitat types was variable among the juvenile rearing studies, and such variability would be expected to affect the form of a resulting HSC curve. Although some of the habitat type data has yet to be fully evaluated, most of the effort data is in a form (dive times) that is difficult to evaluate to determine the relative level of sampling effort among habitat types. Consequently, utilizing habitat use data from the various juvenile rearing studies requires accounting for potential differences in sampling effort among habitat types (suggestions to be discussed below).

A lack of consistency in the cover coding systems will make use of combined rearing data difficult without simplifying the various codes into a very general description. Because cover codes are often difficult to apply successfully in PHABSIM studies, a simplified code may be desirable as long as it is felt to be effective in describing the habitat requirements of the various species and life-stages.

The rearing data collected during the intermediate-scale and fine-scale surveys did not include measurements of mean column velocity at the focal positions of observed fish. Focal velocity data is available for those fish observations and comparative mean column and focal velocity data are being collected this year. If a strong relationship can be established between the 2002 focal and mean column velocities, that relationship can be used to estimate mean column velocities for the 1999-2001 intermediate-scale and fine-scale data.

The relative suitability of deeper water is poorly defined because most of the juvenile rearing data focused on shallow, margin areas. Only two deeper transects were sampled using SCUBA during the 1992 juvenile rearing survey; the remainder of the sampling was conducted from the surface. Therefore, the data and subsequent HSC curves can only be expected to represent suitability to the depth readily visible from the surface. Although biologists experienced with working in the Feather River have noted that fish densities are extremely low in deeper water, the assessment of suitability at deeper depths has great influence on PHABSIM results and is often a topic of disagreement. The determination of relative suitability of deeper water is a topic that will require further data collection (see Phase 2 discussion below).

<u>**Task 2—Review Habitat Modeling Simulations**</u>

Task 2 Category 1: Applicability of PHABSIM to Large Riverine Systems

DWR (1992) states that the Instream Flow Incremental Methodology is the most widely used and defensible technique for assessing instream flow requirements of fish. The IFIM includes a wide variety of methods of varying complexity, including sophisticated models such as Physical Habitat Simulation (PHABSIM). PHABSIM is described as having been developed to calculate the quantity and usage of physical habitat within a stream or river system given the channel structure, flow, and aquatic species criteria. Beyond this general statement, DWR provides no specific justification that the results of a PHABSIM study would be specifically applicable to a moderately large riverine system such as the Feather River. However, DWR did attempt to correlate WUA habitat indices to chinook salmon spawning distribution in their study area, although with mixed results (Sommer et al. 2001).

Review Note: It has been broadly documented that the IFIM is the most widely used and defensible technique for assessing instream flow requirements for fish. This has been true in the general sense for quite some time (Reiser et al. 1989) and has been confirmed very recently (Bovee et al. 1998; Dunbar et al. 1998; Tharme 2002), although there is divergence on the particulars. The terms "widely used" and "defensible" generally apply to the IFIM as a concept when applied as the methodology was intended. That is, as a decision-support system designed to help natural resource managers and their constituencies determine the benefits or consequences of different water management alternatives (Bovee et al. 1998). There have been many efforts to plagiarize the established credibility of the IFIM to support particular agendas, the most popular of which is to use PHABSIM alone as a multiple attribute instream flow standard-setting method (Stalnaker et al. 1995). The DWR study plan for the Feather River instream flow study (DWR 1992) clearly outlines their intention to apply the IFIM as it was designed, "to address the major issues of the water transfer…with emphasis on the importance of changes in habitat resulting from different levels of instream flow." Several other studies which are components of the IFIM (sediment transport, temperature modeling, riparian habitat, recreational use) were also implemented.

The specific applicability of the PHABSIM component of IFIM to the Feather River is less clear. Most PHABSIM studies do not sufficiently document the physical character of the target rivers by common metrics (average width, depth, velocity, substrate, gradient, sinuosity, hydrology, temperature, etc.) to say the Feather River falls within the range of those successfully studied. Nor is there much in the way of species biomass correlations to WUA over time in similar rivers to say the fish populations in the Feather River are expressly responding to the habitat variables incorporated into PHABSIM. It can only be somewhat reasonably inferred that PHABSIM will apply to the Feather River based on approximate parallels, suggesting caution in the interpretation of results.

As a general statement, PHABSIM tends to work well when a species or life stage is capable of physically utilizing the entirety of a river channel and to actively seek areas most suitable to its life history needs. Good results can be expected for strong swimming adult fish or for spawning activity that correlates well to specific combinations of velocity, depth, and substrate. Less reliable results can be expected for weak swimmers that can only barely hold position (pelagic fry), for those species that utilize micro-habitat niches poorly sampled by hydraulic measurements (amphibian egg masses behind rocks), for schooling species whose behavior is driven more by association with others and less by physical habitat variables, or for those species with poorly studied behavioral traits (territorial loyalty).

The fry life stage of salmonid fish species can fall into several of the above "less reliable" categories. They are weak swimmers, so they have little choice about what habitat they can occupy; they are very small, so their physical space can vary from their surroundings at only a short distance; they can be schooling, so many individuals may occupy a space because of proximity to others; and they are highly susceptible to predation, so they can be cryptic and seek an unknown variety of cover types that may or may not be incorporated into a particular study. The classic examples of salmonid fry WUA indices being counter-intuitive ("wrong") are those which show higher habitat values at the lowest possible flows, when it is generally agreed by biologists that conditions would be unsuitable. The standard explanation for this is that some important physical micro- or meso-habitat element was not included in the study. This reasoning is hard to fault and even harder to experimentally test, mostly because few are willing to take the risk of considerable fish mortality.

Some instream flow studies incorporate concepts of cover type, distance to cover, and relative value of cover type (Hardy and Addley 2001), or restrict possible habitat area to stream margins only (Parametrix and Hardin-Davis 1984) to minimize or avoid "wrong" results for salmonid fry. These flow studies generate WUA values that decline with decreasing flow (and are therefore satisfying to the modelers), but they have yet to be correlated to biomass or carrying capacity, as has been done for larger fish (Bovee et al. 1994; Jowett 1992). The DWR studies actually incorporated a similar cover feature by linking suitability for fry and juvenile chinook salmon to only those cells having cover, which were only those adjacent to the streambanks.

Task 2 Category 1: Sensitivity of WUA to Hydraulic Data and Modeling Variables

Instream flow modelers generally agree that PHABSIM study WUA results are more sensitive to species habitat suitability criteria than to the various elements of the hydraulic models. That is, WUA will change more in response to variation in HSC than to variation in water surface elevation or velocity simulations, habitat type representation, transect weighting, cell width, discharge accuracy, and related parameters. While this broad statement places emphasis on appropriate HSC, it does not absolve the hydraulic data base from culpability in WUA errors. There are plenty of ways that hydraulics (and substrate/cover coding) can lead to poor or misleading WUA, just that most of them have to be fairly serious before they will become significant. Unfortunately, there are no rigorous, statistically-derived guidelines available within the published literature or PHABSIM training manuals to indicate which parameters are important and which are not so important. Most of the guidelines are "rule-of-thumb" and the result of either modeling experience or limited sensitivity testing. Most are also context-sensitive (stream channel character, hydraulic variability, species habitat needs, etc.), meaning that definitive statements about parameters are likely to be excessively rigorous in some cases and insufficient in others.

Typical rule-of-thumb guidelines for hydraulic modeling govern the number and placement of transects, the level, number, and range of measured calibration flows, the minimum accuracy for discharge calculation, the characteristics of velocity adjustment factor patterns (an internal velocity error compensation), the mean error, slope, and intercept of stage-discharge rating curves, the allowable range of various beta coefficients, and the acceptable range of discharge and velocity data extrapolation. There are many others too numerous to list. Some modelers or reviewers know the reasons for and flexibility of the guidelines and others do not. Knowing what to look for in a PHABSIM study is unfortunately mostly a function of experience and there has been little training readily available for many years. It is very common for PHABSIM studies to be accepted at face value when inconsistencies, improbabilities, and even fatal flaws remain hidden inside the black box (Payne 1988).

Review Note: The specific problems identified in this review of the Feather River instream flow studies include low representation of common habitat types (e.g. straight flatwater pools), unrealistic simulation of velocities on stream margins, and difficulties modeling complex habitat types like island complexes, especially double-weighting partial split channels. After these problems are addressed in Phase 2 and the models are judged acceptable, additional sensitivity testing can be performed to increase confidence in results prior to alternatives analysis or flow regime decision making.

The use of binary spawning criteria is not recommended and should not be incorporated into the reanalysis of existing and additional data as part of Phase 2 work. Binary (either no or full suitability) criteria are sometimes used in instream flow studies to create absolute thresholds for WUA suitability and eliminate the potential for less than perfect probabilities to influence WUA. The consequence of these types of criteria, however, is to eliminate from consideration much habitat actually utilized by fish (see "Task 1B Category 2 Chinook Spawning HSC) and to introduce confusing "jumpiness" to WUA functions as velocity or depth for individual cells crosses the thresholds. Figures 3 and 4 illustrate both of these effects for the upper segment and lower segment, respectively. Binary criteria generate much lower WUA by elimination of partially suitable cells and also change which flow might be considered "optimum" for spawning. For the Feather River studies, spawning WUA is already a very small percent of total river area (under 2%) as a result of low transect representation of spawning areas, and the binary criteria reduce it further. These very low WUA percentages of total area produce unreliable results that are highly subject to minor errors or discrepancies in the hydraulic modeling. Additional targeted spawning transects and use of standard probability criteria would help generate a more reasonable model.

Task 2 Category 2: Habitat Quality by Cells

The weighted usable area index to probable habitat suitability is computed from the sum of individual cell suitabilities along transects within the study area. The area of each cell is defined as half the distance between adjacent cells, times a length for the transect assigned through habitat mapping. The length is really an expansion factor representing the percentage of habitat type of the transect, rather than a physical distance upstream and downstream of the cell, as commonly perceived. The RHABSIM© computer version of the PHABSIM software allows a visual display of cells (boxes) within a study site, with the size of each cell proportional to its weighted area. Weight given to all cells along a transect is represented by the vertical extent of the cells, and the spacing of each cell is represented by the width. The probable suitability of each cell (derived from the product of velocity, depth, and substrate/cover suitability) is displayed in color code in 0.2 increments between zero and 1.0. These color coded plan view maps are useful for evaluating the abundance and distribution of suitable habitat area throughout a study reach. Figures 5 and 6 illustrate the probable habitat suitability by cell for juvenile chinook salmon in the upper study segment (upper segment) of the Feather River for 200 cfs and 1200 cfs, respectively.

Review Note: On close inspection, these types of study area plan views can reveal an abundance of useful information. The most obvious is the dominance of the three straight flatwater pool transects, which together comprise 62.29% of the reach by transect weight (Table 4), followed by the two island bar complex pools at 19.39%. The remaining ten transects and cells are very small proportionally and will therefore have little influence on WUA relationships for this species life stage. Second is the difference in suitability of the majority of cells between the two flows, which changes from 0.2-0.4 (blue) at 200 cfs down to 0.0-0.2 (purple) at 1200 cfs. While the percent usable area changes very little (23.16% to 23.80%) and weighted usable area increases only 16.4% (59081.5 to 68741.2 square feet per 1000 linear feet), there is a large increase in cells with higher suitability in the range of 0.8 and above. This is an example of roughly equivalent WUA at two flows where the lower flow has a large area of low suitability and the higher flow a smaller area of higher suitability.

Comparison of the two plan views also reveals more subtle (and potentially problematic) differences. The next-to-last transect (Weir Riffle straight flatwater pool near top of figure) has a shallow shelf on the left bank that, when inundated, generates the great majority of suitable area present at the 1200 cfs flow. More detailed examination of this transect for the individual variables (Figure 7 velocity, Figure 8 depth, Figure 9 substrate/cover) shows the WUA to be driven by substrate/cover (attribute 1) suitability, and only the Weir Riffle pool has any substantial area coded as potentially suitable. (The above-center Robinson Riffle island bar complex run/glide does also, but has only a 5.09% weight and is a double-weighted side channel.) It is rarely desirable to have WUA results deriving mostly from one area of one transect. A different decision about consolidating substrate and cover coding (instead of 1.0 with-cover and 0.22 without-cover) is also likely to give a very different result.

One final piece of information that can be derived from a plan view concerns the separation or width of cells across the transects (fine vertical black lines in the figures). Several transects, particularly the heavily weighted pools, have cells that are very wide in comparison to the river width and to other transects. Some cells in the upper reach are as wide as 20 feet, and one is 30 feet. Cell stationing in the lower reach is similar on a few transects, with one extreme example being 195 feet wide. As flow changes and wide cells change in and out of suitability, there will be large or jumpy changes in the composite WUA function, which can sometimes lead to incorrect interpretation (false inflection points, for example). Stationing for cell definitions along transects should be roughly consistent and closely spaced, particularly along stream margins that become wetted with increasing flow.

Task 2 Category 2: Two-Dimensional Depth-Averaged Hydraulic Modeling

Traditional PHABSIM studies such the one applied by DWR to the Feather River have utilized one-dimensional hydraulic models to generate patterns of changing depth and velocity with discharge. A one-dimensional model represents a stream by means of vertical slices (transects) across the channel. Depths are simulated with the rise and fall of a single, level (in most cases) water surface. Velocities are simulated in various ways based on measured data at each cell or by general depth functions, and in all cases are modified to be consistent with stage and total discharge. Two-dimensional models start at a downstream transect with a known stage-discharge relationship, and depths and velocities are propagated upstream through a defined grid of x, y, and z coordinate points. Fluid dynamic equations are sequentially solved to balance depth and velocity patterns within the cells of the grid, and can be modified by variable roughness at each grid point. Multiple iterations of the model are required before an equilibrium state is reached for any given discharge, and the process is repeated for other simulated discharges. No other measured depth or velocity calibration data are entered into the model, although results can be modified by changing grid roughness values to roughly match known data.

Testing and application of two-dimensional hydraulic models to compute habitat suitability indices has been underway for over a decade (LeClerc et al. 1995; Addley and Hardy 2002). While there has been some testing of the accuracy of two-dimensional simulated velocity patterns (Waddle et al. 2000), there has been only one that compared weighted usable area between the one and two-dimensional methods. Hardy and Addley (2001) found normalized habitat relationships from the two methods in the Klamath River to be fundamentally similar in terms of the functional relationships and flow ranges at which maximum habitat conditions were predicted. Two-dimensional models are generally considered appropriate where a study site contains flow splits, islands, complex channels, and eddies or where habitat suitability is being evaluated by patch or associative metrics (Waddle and Steffler 2001). Cost can be a factor, with 2-D costing as much as ten times as 1-D for novices to apply the more complicated modeling method.

Review Note: A combination of one and two-dimensional modeling is probably warranted in Phase 2 of the Feather River instream flow study. The upper segment (upper segment) and particularly the lower segment (lower segment) contain numerous examples of split channel habitats. Some of these were included in the 1-D DWR studies, such as island bar complexes (although with difficulty; a few transects had to be dropped because of poor calibration), and some were not, such as lateral bar complexes. The lateral bar complexes could be targeted for 2-D study to strengthen the overall coverage of modeled habitats. Results could be merged with existing data to create a composite analysis utilizing the strengths of both 1-D and 2-D approaches.

A secondary value of a 2-D model (and separate from modeling existing habitat) would be application to future river restoration sites. Two-dimensional models require only a downstream rating curve and detailed topographic grid to compute depth and velocity patterns for a habitat suitability analysis. If an engineer can create a "future" topographic grid at a site with a known downstream rating curve, a 2-D model will function with reasonable accuracy. Habitat index modeling can then be used as feedback to refine the proposed restoration design for maximizing desirable habitat features. This type of future condition projection analysis is beyond the capacity of 1-D models.

Task 2 Category 2: Methods for Validating 2D models

Both one- and two-dimensional hydraulic models produce patterns of depths and velocities that can be linked to habitat suitability criteria and produce WUA indices of habitat with discharge. Validation of model predictions can be done on two levels, one by testing hydraulic patterns and the other by testing actual fish distributions. Testing predictions of hydraulic patterns against observations can be accomplished relatively easily, although poor matches may or may not have any actual significance. Some researchers hold the opinion that accurate hydraulic predictions are essential to have confidence in WUA indices (Kondolf et al. 2000). Other work, however, has shown that the linkage of hydraulics with HSC reduces the influence of potential hydraulic errors (which have a tendency to compensate), giving similar WUA results with either a little or a lot of calibration data (Payne 1988).

Validating WUA indices is more difficult because WUA is not an actual area that can be physically located in the field once it has been computed. Habitat suitability criteria are zero-to-one probability functions derived from frequency-of-use histograms of fish observations. A given combination of velocity, depth, and substrate/cover values at each cell (actually a vertical measurement or computational point) within a study area is converted to equivalent suitability in the HSC, multiplied together, and weighted by cell width and transect representation. Thus, weighted usable area (WUA) is really a probable suitability index (PSI) that measures the likelihood a fish will occupy any given spot in a river at a given discharge. The ability to validate a PSI is limited by the need for a relatively large sample size (to reproduce probability and minimize the effect of chance), limitations imposed by spatial variability (a fish may respond to conditions next to the measurement point rather than directly at the measurement point), and several other biotic and abiotic factors. In its simplest form, validation of WUA consists of looking for fish along transects (1-D) or within grids (2-D) and comparing actual distribution to localized WUA. A strong correlation of fish locations with high PSI would constitute "validation".

Alternatively, WUA can be validated by correlation with fish population or biomass data over time. By this method, several years of biological data are plotted against either average or critical WUA values, depending on what metric is believed to control the populations. The best example of this validation method is Nehring and Miller (1987) and Nehring and Anderson (1993), where the WUA values during the spring fry emergence period correlated strongly with adult trout populations two years later. The primary disadvantage of population level correlation is the need for a lengthy study period (up to ten years), accurate population data, a limited critical period that can set population levels, and minimal variability in the hydrologic window. Neither validation method has been commonly applied to instream flow studies.

Review Note: The WUA relationships from existing DWR Feather River instream flow studies were used in an evaluation of chinook spawner distribution between the upper and lower reaches. This evaluation found spawner distribution to be reasonably correlated with PHABSIM model predictions, although other factors could also be involved (Sommer pers. comm.). A validation similar to this one could be repeated after revised results from Phase 2 studies are completed.

RECOMMENDATIONS

Collect Additional Targeted Hydraulic Data

Analysis of the existing hydraulic data base for the DWR instream flow studies indicates that there are not enough transects available to adequately represent the current morphology of the Feather River and generate robust WUA functions. The specific reasons for this conclusion are 1) high flows have caused channel change since the transects were first measured and some new data is warranted, 2) common habitat types are represented by too few transects, especially shallow flat water pool, 3) significant habitat areas were not included in the original study, such as lateral bar complex, 4) transects were not placed to specifically represent chinook salmon spawning habitat, 5) the study site selection process description was incomplete and appeared somewhat subjective, 6) only half of some split channel transects were used and given double weight, and 7) many transects are calibrated with only two instead of three or more stage-discharge pairs.

Additional data collection under Phase 2 should be conducted according to standard, established PHABSIM methods, including reach delineation, macrohabitat delineation, transect/site selection and placement, flow level determination, depth, velocity, and substrate/cover data acquisition, computer model construction and calibration, species evaluation and WUA computation, analytical procedures, further interpretation, and time series analysis. The previous approach to reach delineation, macrohabitat delineation, and transect/site selection and placement was thorough and defensible and should be adequate for Phase 2. At least six new transects are recommended to be placed in pool habitat in both the upper segment and lower segment, along with another six targeted spawning transects in both reaches (24 total). The target for weight of any given transect of any macrohabitat type should be 5% or less to minimize uncertainty. One 2-D site in each reach should also be selected in lateral bar complex habitat that includes the entire habitat unit.

Recalibrate the Amended Hydraulic Data Base

Once the gaps in the hydraulic data base are corrected, all original transect and supplemental hydraulic data should be calibrated to current acceptable standards. Issues to be addressed for one-dimensional modeling should include variation in flow computation by transect, stage-discharge rating curves (e.g. mean errors, slopes, intercepts), velocity simulation patterns (especially stream margin velocities), range of hydraulic simulation, and velocity adjustment factors. For two-dimensional modeling the files will need to be calibrated to show appropriate velocity magnitude and direction patterns, realistic water surface elevation slopes and directions, reasonable Froude numbers, and satisfactory grid density and triangulation assignment.

Determine the Habitat Suitability of Deep Water

One of the potential data gaps remaining in the DWR micro-habitat database is the assessment of deeper water areas for rearing juveniles. Because most of the surveys were conducted near the stream margin and from the water's surface, relatively little effective effort has been allocated to deeper water. Consequently, defining the suitability of deeper water for HSC will be highly subjective and may be prone to disagreement. A traditional method of assigning suitability to deeper water is to keep the value at 1.0 into infinity. Although this decision may be appropriate for some species and life-stages (e.g. adult sturgeon), for others it is likely to yield unrealistic results in a PHABSIM analysis. Keeping in mind that HSC are probability-of-use criteria, while it may be true that juvenile chinook salmon, for example, can be found in deep water, it is less likely that they will be found there with the same probability as in shallower water.

Biologists working on the Feather River have indicated that chinook salmon spawning in deep water is extremely unlikely due to the unavailability of suitable gravels and flow characteristics in deeper areas, and thus the spawning HSC curve should follow the decline in use to low suitability in deeper water. Biologists working with juveniles have likewise indicated that juveniles are rarely observed in deeper water away from the margin areas. Most chinook salmon and steelhead emigrate from the Feather River at smaller sizes and thus few remain that would be expected to utilize deeper, offshore areas. The low densities of larger fish would make an assessment of deep water suitability difficult; however a study designed specifically to compare densities of fish at different depth intervals is likely to yield a general relationship between depth and fish densities. Such a relationship could then be used to scale the suitability of deeper water in a manner similar to the Gard method of adjusting deep water suitability for spawning (Gard 1997).

Create New Combined and Adjusted HSC

After a continuation of the analysis of the existing DWR micro-habitat data and the ongoing 2002 results, new HSC should be developed for use in the Feather River . Combining data from the three juvenile rearing studies will offer a large data set for HSC development. Various alternative approaches to combining the data should be attempted because of the difficulties associated with determining sampling effort among the habitat types. One option is to first generate separate HSC for pools, run/glides, and riffles. Then, each of the three data sets would be weighted according to the relative fish densities in each habitat type (so the habitat type with the highest densities would have the highest weighting factor). After weighting, the three data sets would be combined and normalized into an HSC curve. This method essentially simulates an equal-area sampling approach, where the relative number of fish observations per habitat type is determined by the density of fish in each habitat type. If a comparison of the weighted HSC and habitat availability data (also weighted to simulate equal-area sampling) suggests habitat limitations, the option of developing some form of use/availability (ratio) HSC would be explored. Other forms of HSC, including binary HSC, "envelope" HSC (Hardy and Addley 2001), or "composite" HSC (TRPA 2002) will also be evaluated once the 2002 data become available. All HSC developed from the DWR micro-habitat studies will be compared to HSC developed from other large California rivers.

Validate the New Final HSC

Direct observation surveys within 1D or 2D modeling reaches surveyed during Phase 2 should be used to validate the ability of new site-specific (or existing) HSC to successfully predict fish habitat use. See the discussion under "Task 2 Category 2: Methods for Validating 2D Models" for details.

PHASE 2 SCOPING PROCESS

These recommendations should be pursued under the instream flow study scoping process as defined by the IFIM to include all interested Oroville Project Relicensing resource agencies and stakeholders. The first step would be to distribute this evaluation report for review, discussion, revision, and concurrence as to the adequacy of existing data and need for and amount of additional data. The existing logistic framework established for the overall relicensing process, including technical review by the Environmental Work Group and oversight by the Plenary Group, should adequately serve as an instream flow scoping mechanism.

If these recommendations are adopted, the next step would be to begin implementation of necessary field work in time to take advantage of the current year's field season, starting with selection and placement of new hydraulic transects and study sites. The method outlined for site selection in DWR (1992) would be a good template for identifying candidate sites, and the original decision-making process could be replicated with broader review participation. The transect types identified as deficient in this review were straight flat water pool and known spawning areas, where transects could either be located in previously-selected habitat units or in units given higher star ratings where no transects had been placed. Candidate sites for 2D hydrodynamic modeling could consist of the lateral bar complex units previously eliminated from the study in both the upper segment and lower segment.

Phase 2 scoping for supplemental HSC development would follow a similar path as for additional hydraulic data collection, with the exception that implementation of many initial recommendations was started this spring concurrent with scheduled chinook salmon and steelhead field observations. The only significant remaining data gap is the evaluation of deeper water by rearing juveniles, for which a study plan needs to be written and implemented as soon as possible, while the fish are the appropriate size and remain rearing in the river.

Figure 1. Feather River upper segment Combined suitability WUA for Cell for XSEC Weir 1 Chinook Salmon Juvenile at 2,500 cfs

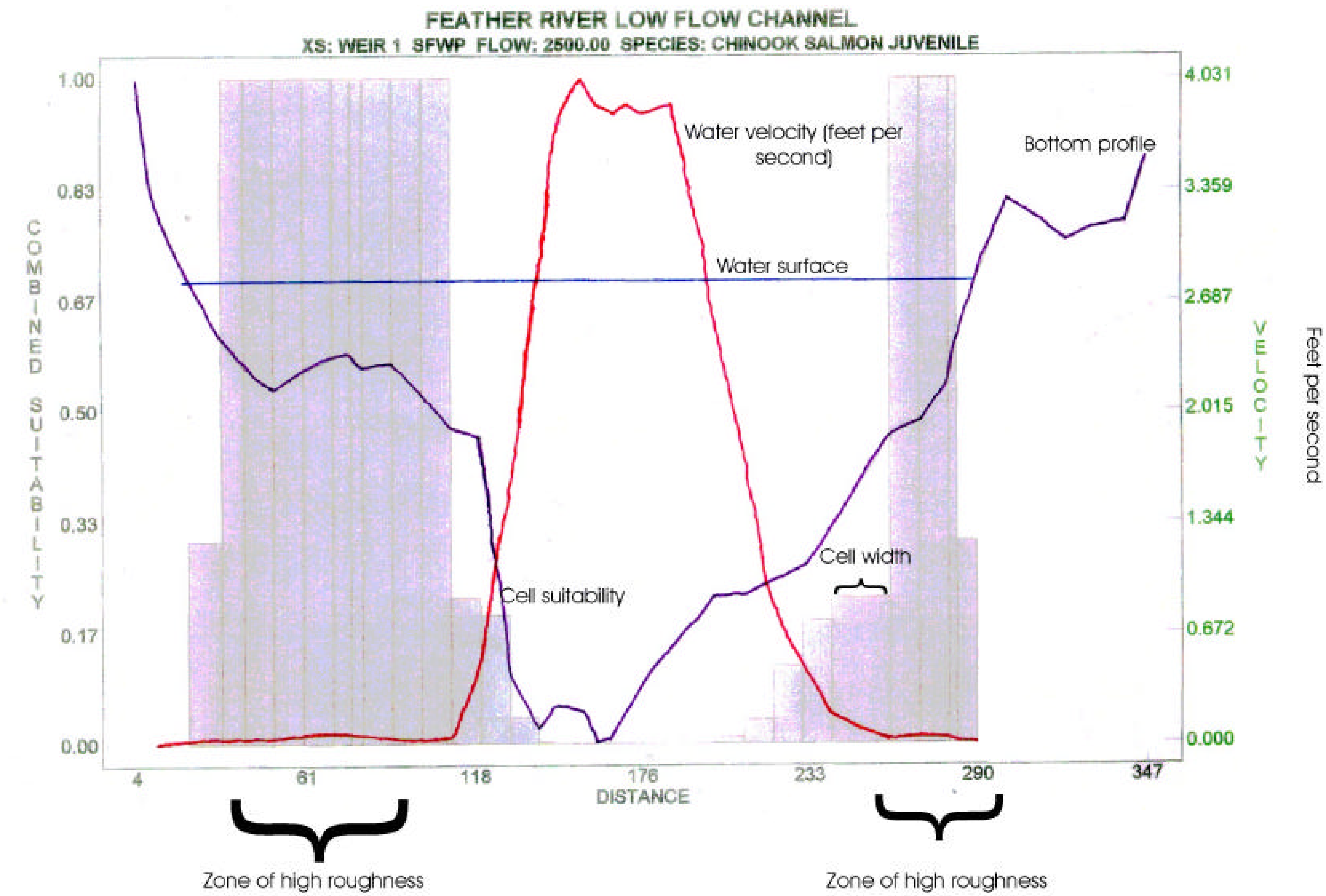


Figure 2. Feather River upper segment Chinook Salmon fry and Juvenile WUA versus Discharge with and without XSEC Weir 1 at Units of Square Feet per 1,000 ft.

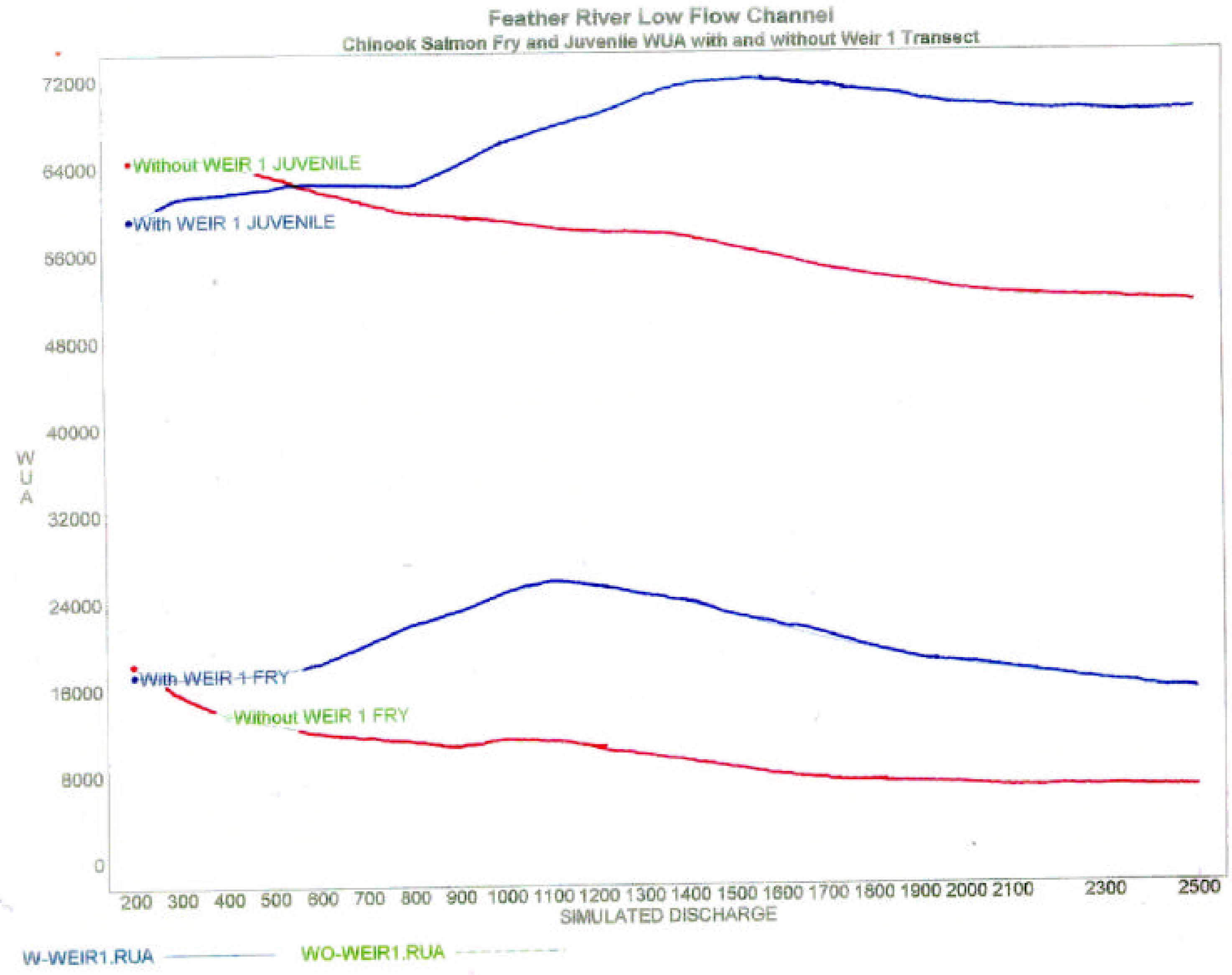


Figure 3. Feather River upper segment Chinook Salmon Spawning WUA with Binary and Standard Criteria as a Percent of Total Area

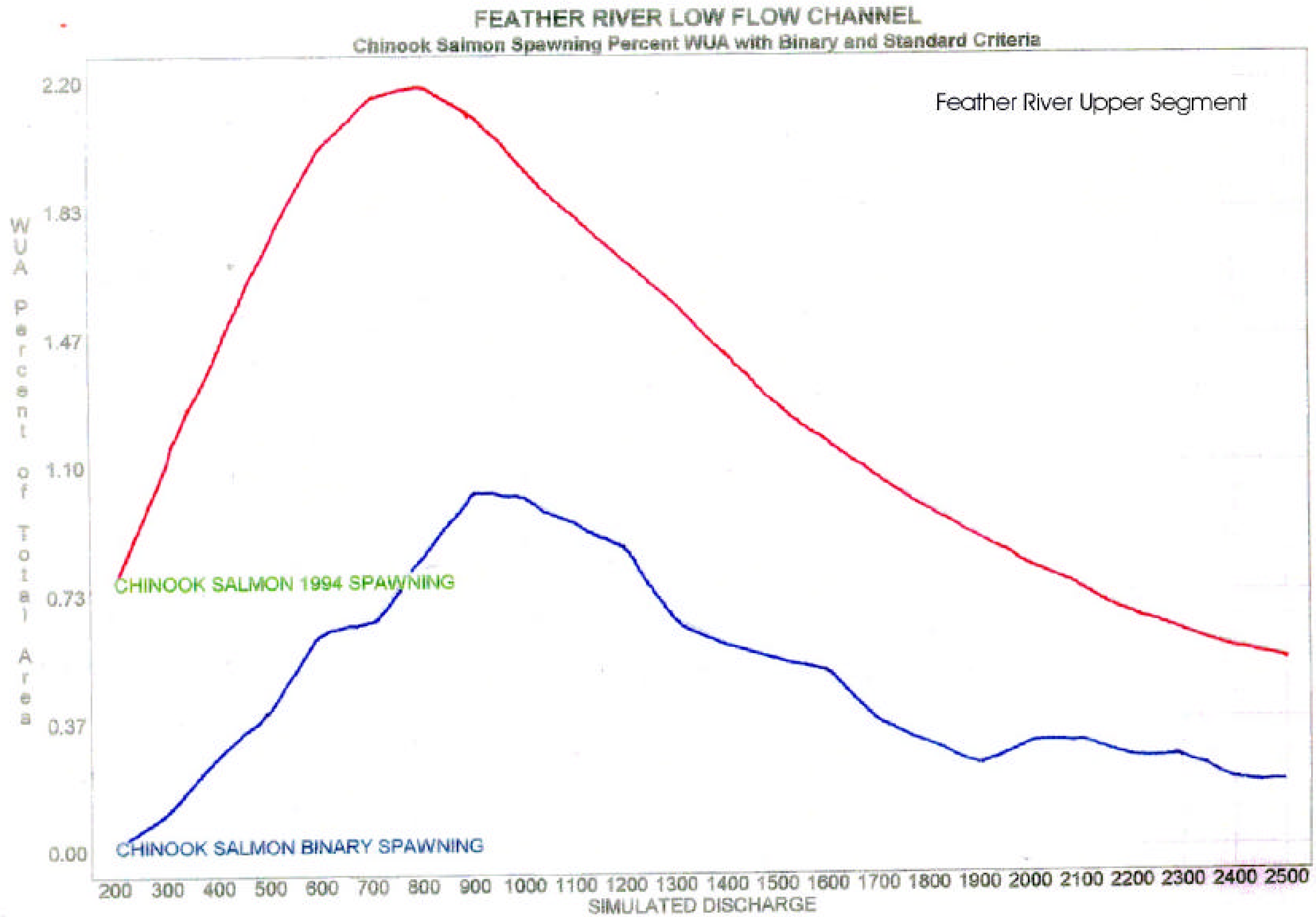


Figure 4. Feather River lower segment Chinook Salmon Spawning WUA with Binary and Standard Criteria as a Percent of Total area

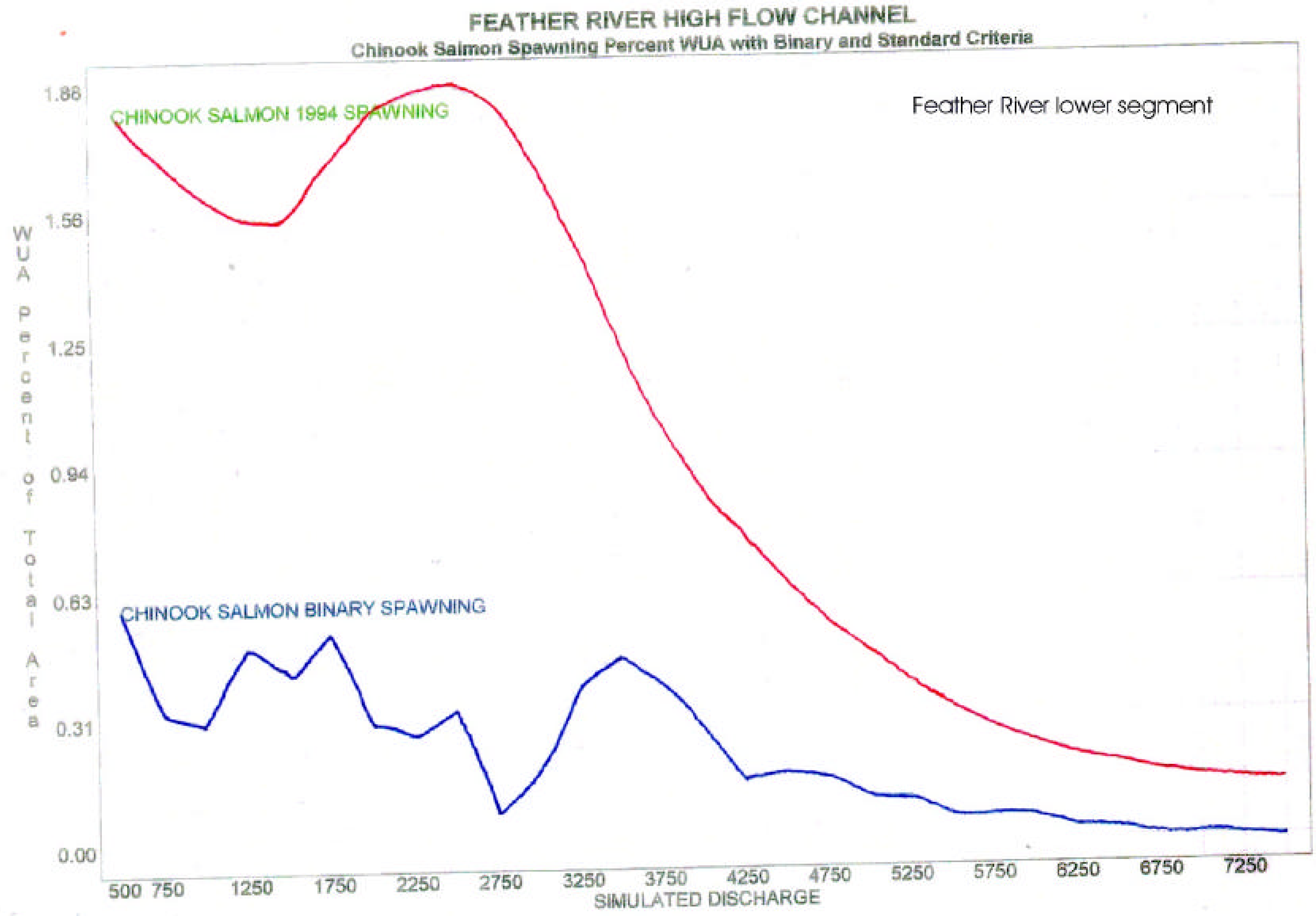


Figure 5. Feather River upper segment Combined Suitability WUA by cell for Chinook Salmon Juvenile at 200 cfs, all Transects with Assigned Weight

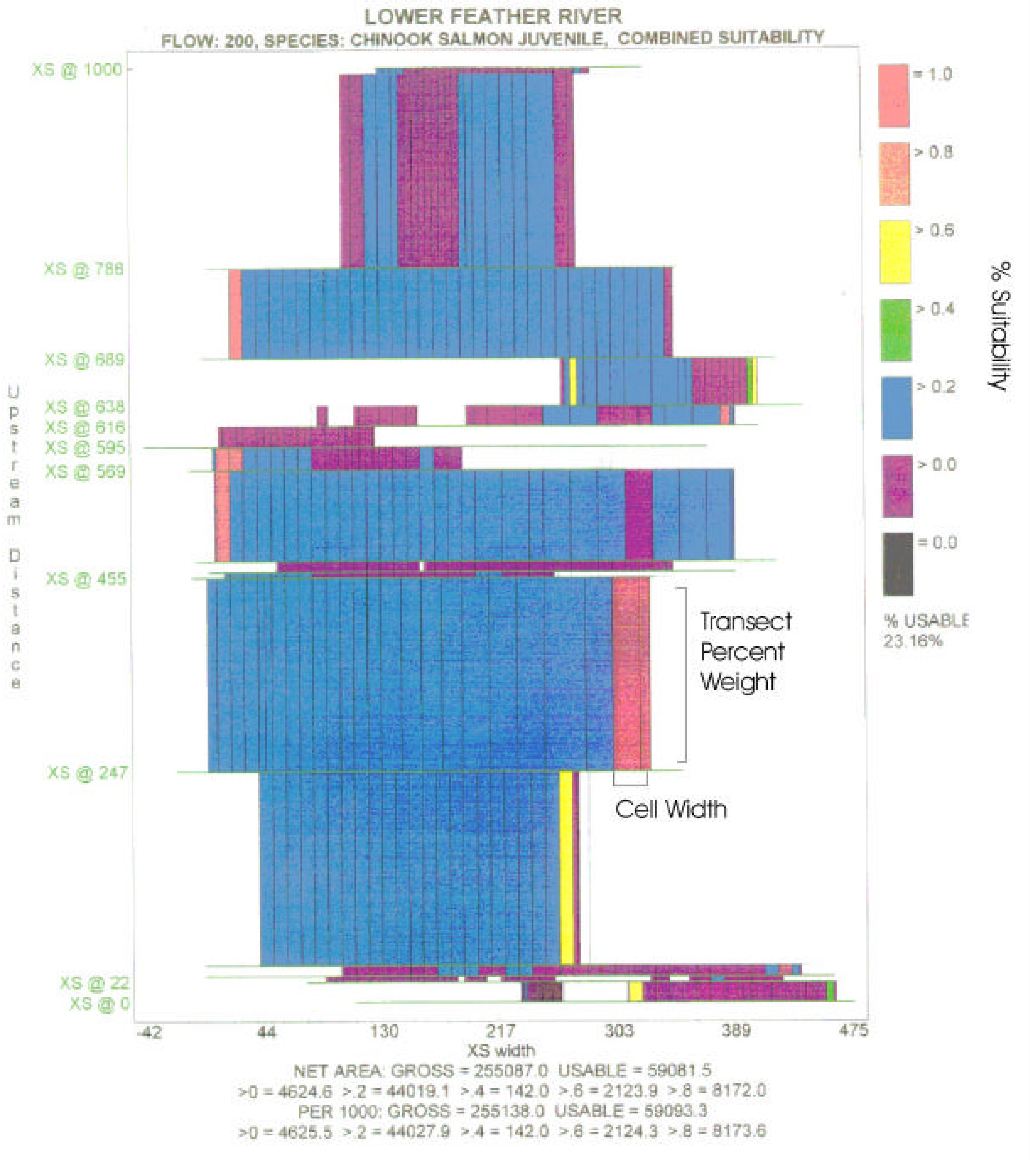


Figure 6. Feather River upper segment Combined Suitability WUA by Cell for Chinook Salmon Juvenile at 1200 cfs, all Transects with Assigned Weight

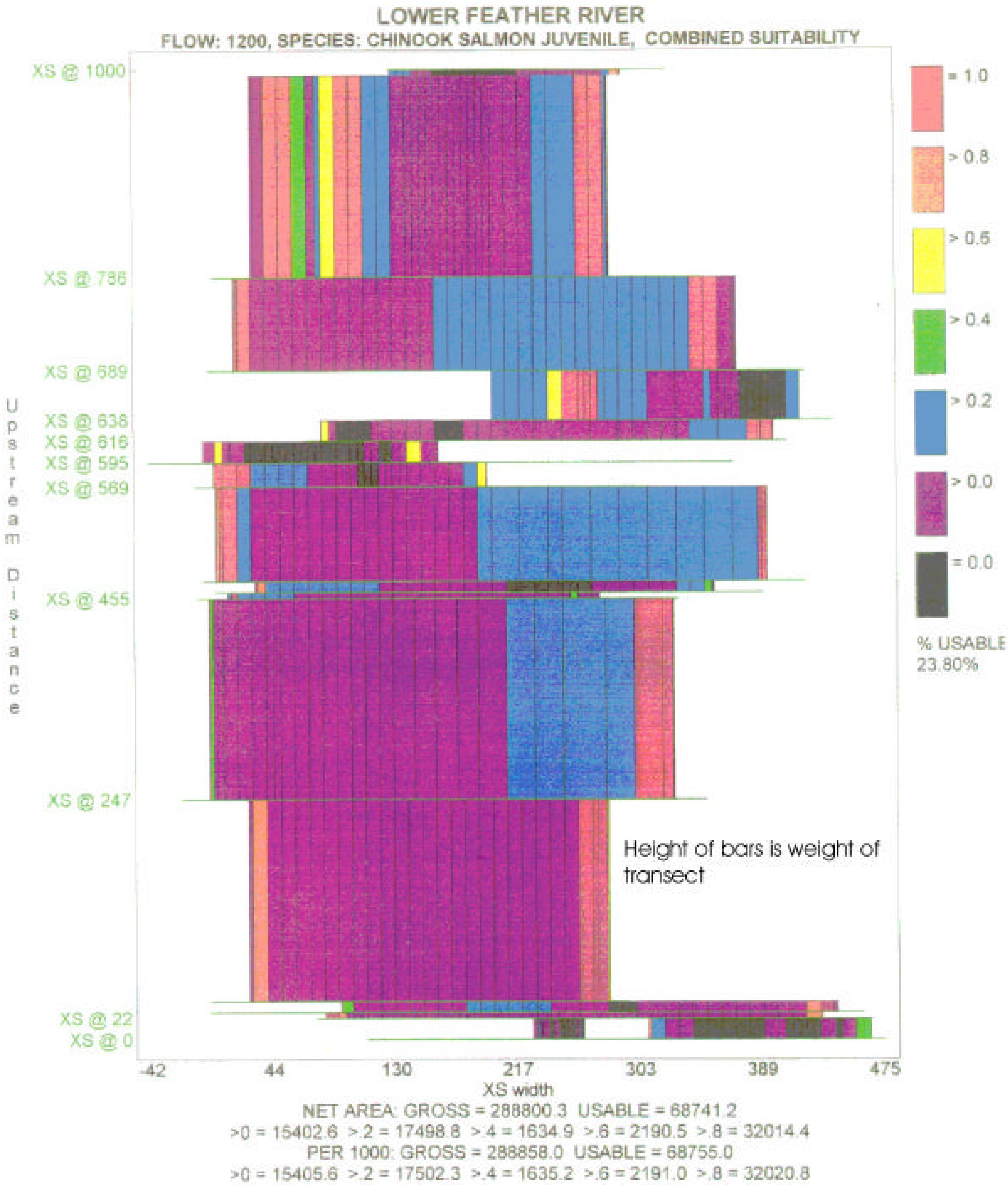


Figure 7. Feather River upper segment Velocity Suitability WUA by Cell for Chinook Salmon Juvenile at 1200 cfs, all Transects with Assigned Weight

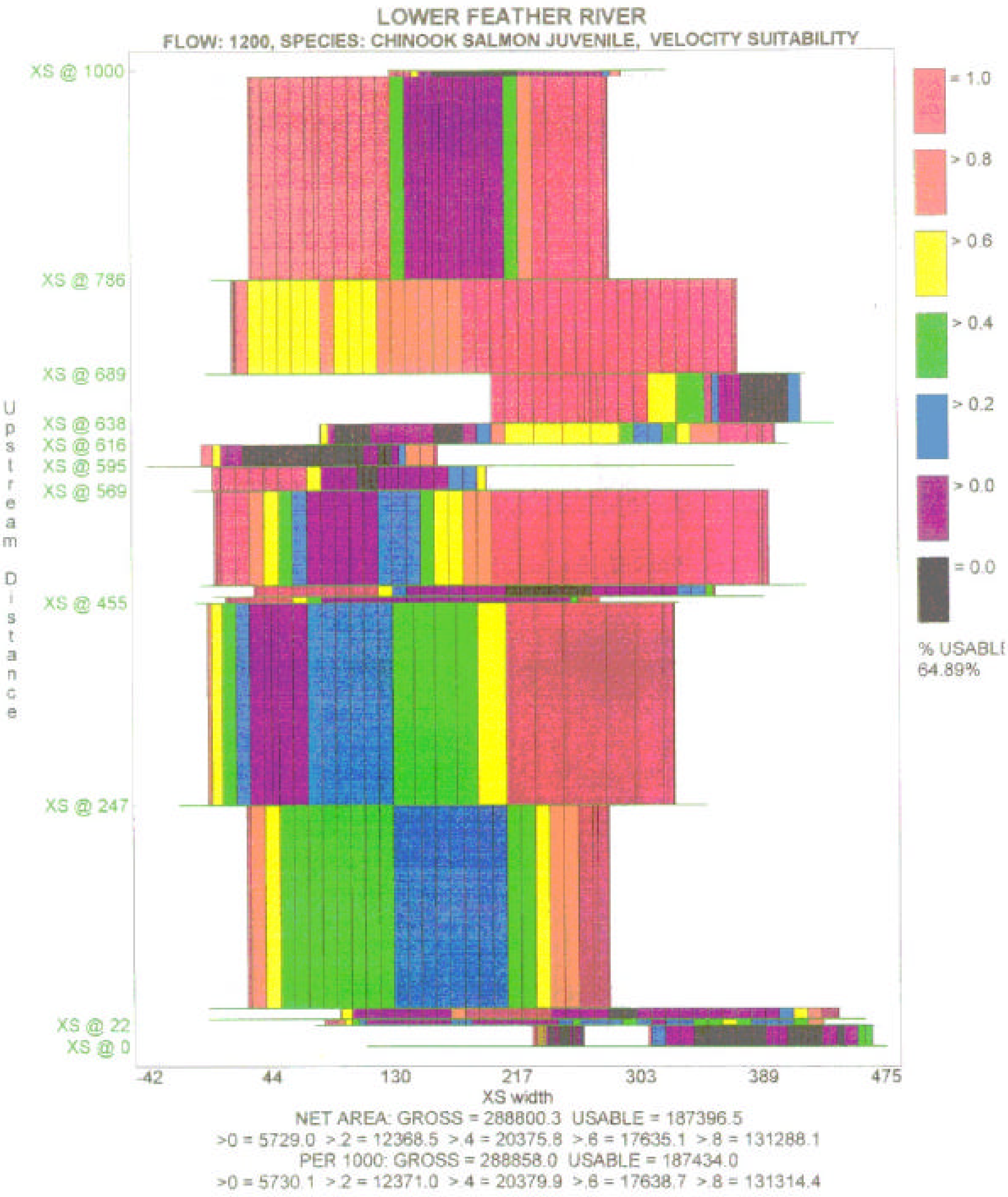


Figure 8. Feather River upper segment Depth Suitability WUA by Cell for Chinook Salmon Juvenile at 1200 cfs, all Transects with Assigned Weight

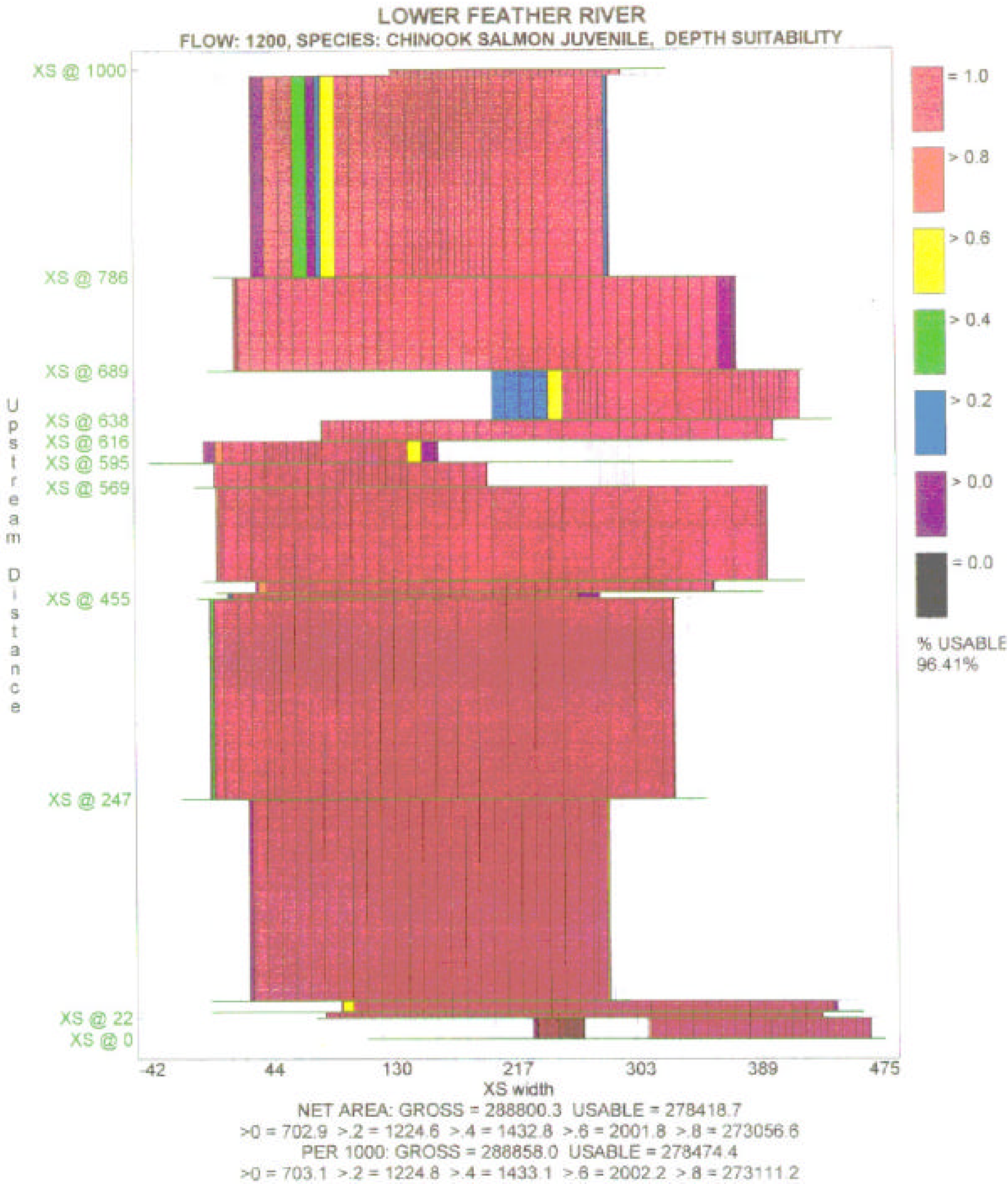
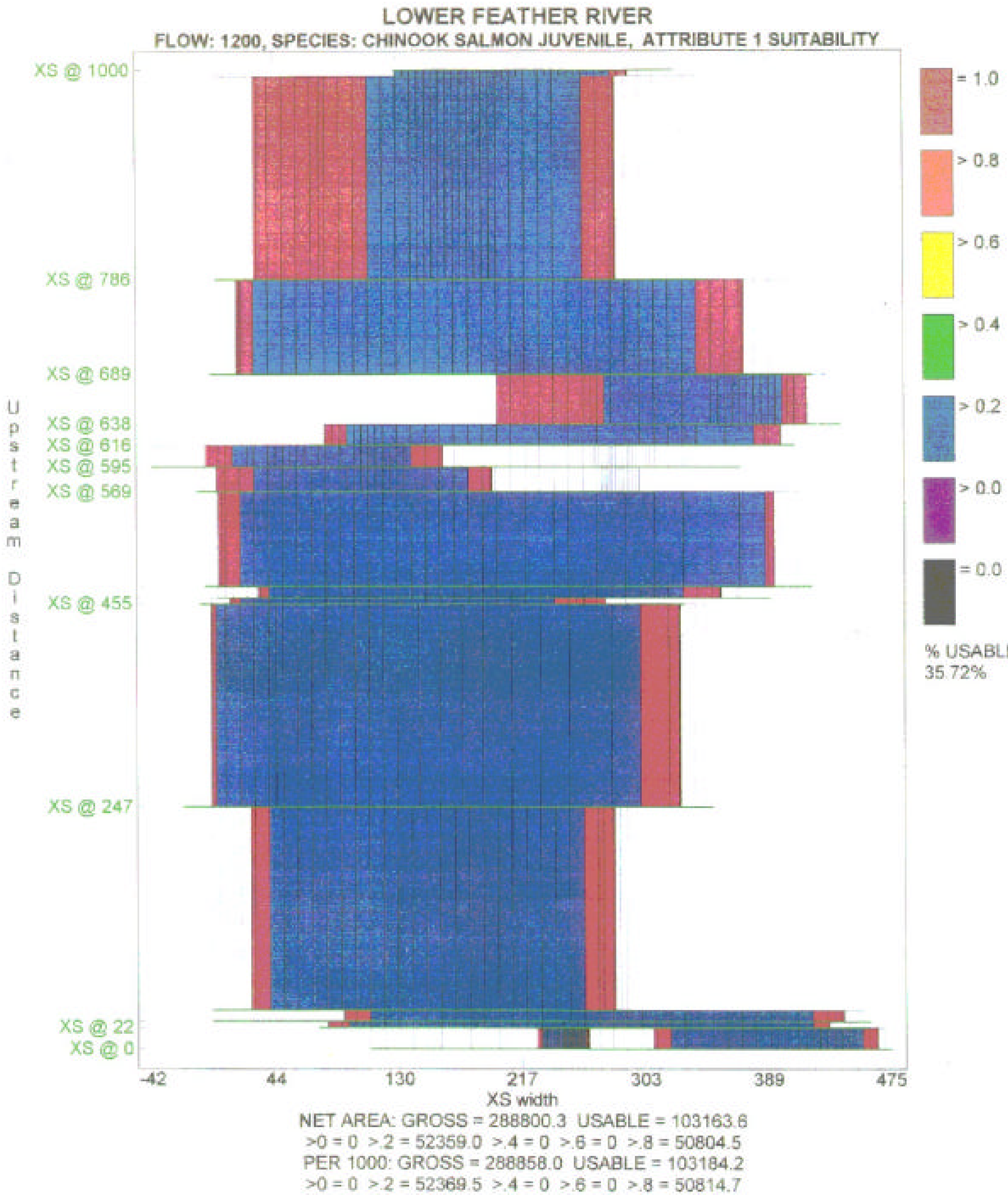


Figure 9. Feather River upper segment Attribute Suitability WUA by Cell for Chinook Salmon Juvenile at 1200 cfs, all Transects with Assigned Weight



REFERENCES

Addley, R.C., and T.B. Hardy. 2002. A decade of two-dimensional instream flow modeling experience. Paper presented at the Fourth International Ecohydraulics Symposium, Cape Town, South Africa, 3-8 March, 2002.

Beak Consultants, Incorporated. 1989. Habitat characterization of the Lower American River. Prepared for State of California Resources Agency, Department of Fish and Game. September 1989. 16pp.

Bovee, K.D. 1986. Development and evaluation of habitat suitability criteria for use in the Instream Flow Incremental Methodology. Instream Flow Information Paper 21. United States Fish and Wildlife Service, Biological Report 86(7). 235pp.

Bovee, K.D., T.J. Newcomb, and T.G. Coon. 1994. Relations between habitat variability and population dynamics of bass in the Huron River, Michigan. National Biological Survey, Biological Report 21. 63pp.

Bovee, K.D., B.L. Lamb, J.M. Bartholow, C.B. Stalnaker, J. Taylor, and J. Henriksen. 1998. Stream habitat analysis using the instream flow incremental methodology. U.S.Geological Survey, Biological Resources Division Information and Technology Report USGS/BRD-1998-0004. viii + 131 pp.

Collier, M., R.H. Webb., and J.C. Schmidt. 1996. Dams and rivers: a primer on the downstream effects of dams. United States Geological Survey Circular 1126. Tucson, AZ. 94p.

DWR (California Department of Water Resources). 1991. Initial results of Feather River spawning survey. Draft Report prepared by California Department of Water Resources, Sacramento, California. Dated 11/8/1991.10pp.

DWR (California Department of Water Resources). 1992. Proposed study plan for the lower Feather River. Report prepared for State Water Resources Control Board by Department of Water Resources in cooperation with Department of Fish and Game. Dated January 1992. 61pp.

DWR (California Department of Water Resources). 1993. Feather River studies: Habitat utilization observations for chinook salmon fry and juveniles. Draft Report prepared by California Department of Water Resources, Sacramento, California. Dated 1/13/1993. 36pp.

DWR (California Department of Water Resources). 1994. Results of lower Feather River instream flow study. Report prepared for State Water Resources Control Board by Department of Water Resources in cooperation with Department of Fish and Game. Draft dated January 27, 1994. 39pp.

DWR (California Department of Water Resources). 2001. Snorkel surveys on the lower Feather River. Draft Report prepared by California Department of Water Resources, Sacramento, California. Dated 11/1/2001. 31pp.

DWR (California Department of Water Resources). 2002. Feather River snorkeling study microhabitat field protocols and Intermediate snorkel survey reach selection criteria. Memorandum prepared by California Department of Water Resources, Sacramento, California. Dated 2/5/2002. 31pp.

DWR (California Department of Water Resources). no date. Study Plan for distribution and habitat use of juvenile salmon and steelhead in the lower Feather River. Memorandum prepared by California Department of Water Resources, Sacramento, California. 5pp.

DWR and CDFG. 1983. Agreement between the California Department of Water Resources and California Department of Fish and Game for the Operation of the Oroville Division of the State Water project for Management of Fish and Wildlife. August 26, 1983.

Dunbar, M.J., A. Gustard, M.C. Acreman, and C.R.N. Elliot. 1998. Overseas approaches to setting river flow objectives. Institute of Hydrology, Wallingford, Oxon, United Kingdom. R&D Technical Report W6-161. 83pp.

EWG (Oroville Project Relicensing Environmental Work Group). 2002. SP-F16 Evaluation of proejct effects on instream flows and fish habitat. Study plan prepared as part of Oroville Project relicensing (FERC No. 2001). Dated February 28, 2002). 12pp.

Gard, M. 1997. Technique for adjusting spawning depth habitat utilization curves for availability. Rivers 6:94-102.

Hardy, T.B., and R.C. Addley. 2001. Evaluation of interim instream flow needs in the Klamath River, Phase II Final Report. Draft report prepared for U.S. Department of the Interior, by Institute for Natural Systems Engineering, Logan, Utah. Dated November 21, 2001. 304 pp.

Jowett, I.G. 1992. Models of the abundance of large brown trout in New Zealand rivers. North American Journal of Fisheries Management. 12:417-432.

Kondolf, G.M., E.W. Larsen, and J.G. Williams. 2000. Measuring and modeling the hydraulic environment for assessing instream flows. North American Journal of Fisheries Management 20:1016-1028.

LeClerc, M., A. Boudreault, J.A. Bechara, and G. Corfa. 1995. Two-dimensional hydrodynamic modeling: a neglected tool in the instream flow incremental methodology. Transactions of the American Fisheries Society 124(5):645-662.

Morhardt, J.E., D.F. Hanson, and P.J. Coulston. 1983. Instream flow: improved accuracy through habitat mapping. In Waterpower '83: International Conference on Hydropower (Vol III, pp. 1294-1304). September 1983, Knoxville, Tennessee.

Nehring, R.B., and D.D. Miller. 1987. The influence of spring discharge levels on rainbow and brown trout recruitment and survival, Black Canyon of the Gunnison River, Colorado, as determined by IFIM/PHABSIM models. Proceedings of the Annual Conference Western Association Fish and Wildlife Agencies, Salt Lake City, Utah. 67:388-397.

Nehring, R.B., and R.M. Anderson. 1993. Determination of population-limiting critical salmonid habitats in Colorado streams using the Physical Habitat Simulation System. Rivers 4(1):1-19.

Parametrix, Inc., and Hardin-Davis. 1984. Initial flow recommendations Yakima River Basin. Document No. 84-1031-0019F. Report to U.S. Department of Interior, Bureau of Reclamation, Boise, Idaho. 32pp.

Payne, T.R. 1988. A comparison of weighted usable area calculations using four variations of the IFG4 hydraulic model. Paper presented at AFS Bioengineering Symposium, October 24-27, 1988, Portland, Oregon.

Payne, T.R. 1988. PHABSIM analytical errors and implications for IFIM. Instream Flow Chronicle, Vol. V, No. 3. Ft. Collins, CO.

Reiser, D.W., T.A. Wesche, and C. Estes. 1989. Status of instream flow legislation and practices in North America. Fisheries 14(2):22-29.

Stalnaker, C.B., B.L. Lamb, J. Henriksen, K. Bovee, and J. Bartholow. 1995. The Instream Flow Incremental Methodology, a primer for IFIM. National Biological Service, U.S. Department of the Interior. Biological Report 29, March 1995. 45pp.

Sommer, T., D. McEwan, and R. Brown. 2001. Factors affecting chinook salmon spawning in the lower Feather River. Pages 269-297 in R.L. Brown, editor. Contributions to the biology of Central Valley salmonids. California Department of Fish and Game Fish Bulletin 179.

Tharme, R.E. 2002. Emerging global trends in environmental flow assessment. Paper presented at the Fourth International Ecohydraulics Symposium, Cape Town, South Africa, 3-8 March, 2002.

TRPA (Thomas R. Payne & Associates). 2002. Habitat suitability criteria for rainbow trout and Sacramento suckers in the Upper North Fork Feather River Project (FERC No. 2105). Report prepared for Pacific Gas and Electric Company, San Ramon, California. 86pp.

USFWS (U.S. Fish and Wildlife Service). 1995. Working paper on restoration needs: habitat restoration actions to double natural production of anadromous fish in the Central Valley of California. Volume 3. 9 May 1995. Prepared for the USFWS under the direction of the Anadromous Fish Restoration Core Group. Stockton, CA.

Waddle, T, and P. Steffler. 2001. Workshop on River 2-D, a two dimensional depth averaged model of river hydrodynamics and habitat. 11-13 October 2001, Fort Collins, Colorado.

Waddle, T., P. Steffler, A. Ghanem, C. Katapodis, and A. Locke. 2000. Comparison of one and two-dimensional open channel flow models for a small habitat stream. Rivers 7(3):205-220.

Williams, J.G. 1996. Lost in space: minimum confidence intervals for idealized PHABSIM studies. Transactions of the American Fisheries Society 125:458-465.

PERSONAL COMMUNICATIONS

Ross, B. 2002. Geomorphologist, California Department of Water Resources, Oroville, CA.

Sommer, T. 2002. Biologist, California Department of Water Resources, Sacramento, CA.

APPENDIX A REVIEW DOCUMENTS AND SOURCES OF INFORMATION

DWR (California Department of Water Resources). 1991. Initial results of Feather River spawning survey. Draft Report prepared by California Department of Water Resources, Sacramento, California. Dated 11/8/1991.10pp.

DWR (California Department of Water Resources). 1992. Proposed study plan for the lower Feather River. Report prepared for State Water Resources Control Board by Department of Water Resources in cooperation with Department of Fish and Game. Dated January 1992. 61pp.

DWR (California Department of Water Resources). 1993. Feather River studies: Habitat utilization observations for chinook salmon fry and juveniles. Draft Report prepared by California Department of Water Resources, Sacramento, California. Dated 1/13/1993. 36pp.

DWR (California Department of Water Resources). 1994. Results of lower Feather River instream flow study. Report prepared for State Water Resources Control Board by Department of Water Resources in cooperation with Department of Fish and Game. Draft dated January 27, 1994. 39pp.

DWR (California Department of Water Resources). 2001. Snorkel surveys on the lower Feather River. Draft Report prepared by California Department of Water Resources, Sacramento, California. Dated 11/1/2001. 31pp.

DWR (California Department of Water Resources). 2002. Feather River snorkeling study microhabitat field protocols and Intermediate snorkel survey reach selection criteria. Memorandum prepared by California Department of Water Resources, Sacramento, California. Email dated 2/5/2002. 3pp.

DWR (California Department of Water Resources). 2002. Feather River juvenile fish studies as they relate to instream flow studies. Powerpoint presentation by Brad Cavallo, California Department of Water Resources, Sacramento, California.

DWR (California Department of Water Resources). no date. Study Plan for distribution and habitat use of juvenile salmon and steelhead in the lower Feather River. Memorandum prepared by California Department of Water Resources, Sacramento, California. 5pp.

DWR (California Department of Water Resources). no date. Aerial photographs taken 10-90 showing channel types, mesohabitat types, and PHABSIM transect locations.

DWR (California Department of Water Resources). no date. Aerial photographs (on CD) taken 9-99 showing mesohabitat types and locations.

DWR (California Department of Water Resources). no date. Feather River IFG4 and habitat suitability files. Diskette received from California Department of Water Resources, Sacramento, California, 2/19/02 .

DWR (California Department of Water Resources). no date. 1991 and 1995 Feather River spawning data. Diskette received from California Department of Water Resources, Sacramento, California, 2/19/02.

DWR (California Department of Water Resources). no date. 1992 Feather River juvenile data. Diskette received from California Department of Water Resources, Sacramento, California, 2/19/02.

DWR (California Department of Water Resources). no date. Fine-scale snorkel data. Email file received from California Department of Water Resources, Sacramento, California, 4/26/02.

DWR (California Department of Water Resources). no date. Intermediate-scale snorkel data. Email file received from California Department of Water Resources, Sacramento, California, 4/26/02.

Sommer, T., D. McEwan, and R. Brown. 2001. Factors affecting chinook salmon spawning in the lower Feather River. Pages 269-297 in R.L. Brown, editor. Contributions to the biology of Central Valley salmonids. California Department of Fish and Game Fish Bulletin 179.

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